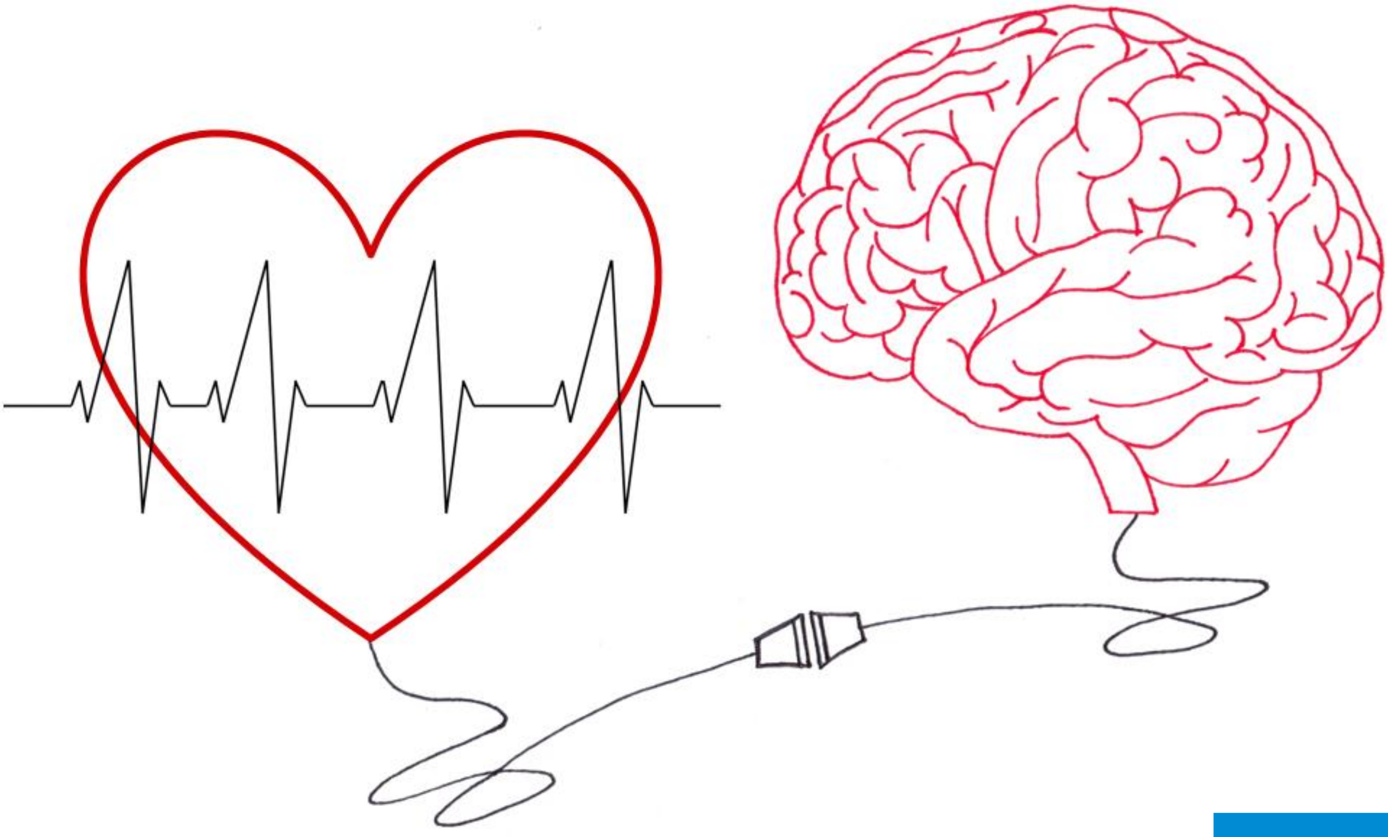
Heart Rate Variability: What Remains at the End of the Day?



2018

DISSERTATION

zur Erlangung des akademischen Grades doctor rerum naturalium (Dr. rer. nat)

vorgelegt der Fakultät für Human- und Sozialwissenschaften der Technischen Universität Chemnitz

STEFAN UHLIG

geboren am 26.03.1987 in Karl-Marx-Stadt

Heart Rate Variability: What Remains at the End of the Day?

Dissertation

zur Erlangung des akademischen Grades doctor rerum naturalium (Dr. rer. nat)

vorgelegt der Fakultät für Human- und Sozialwissenschaften der Technischen Universität Chemnitz

vorgelegt von: Stefan Uhlig
geboren am 26.03.1987 in Karl-Marx-Stadt

eingereicht am: 24.11.2017
verteidigt am: 31.01.2018

Gutachter: Prof. Dr. Udo K. Rudolph, Technische Universität Chemnitz
Prof. Dr. Josef F. Krems, Technische Universität Chemnitz

http://nbn-resolving.de/urn:nbn:de:bsz:ch1-qucosa-233101

TECHNISCHE UNIVERSITÄT
CHEMNITZ

It is only with the heart that one can see rightly;
what is essential is invisible to the eye.

Man sieht nur mit dem Herzen gut,
das Wesentliche ist für die Augen unsichtbar.

Antoine de Saint-Exupery

Danksagung

Wenn das Arbeiten bis tief in die Nacht zum Standard wird, wenn sich Wochenenden inhaltlich kaum von der Arbeitswoche unterscheiden, wenn man sich „Sorry, keine Zeit“ als Formatvorlage abspeichert, wenn man an sich und dem, was man tut, zu zweifeln beginnt oder sich scheinbar unüberbrückbare Hindernisse auftun, dann, genau dann, braucht man Personen in seinem Umfeld, die einem den Rücken stärken. Menschen, die einem sagen, dass das, was man tut, gut genug ist. Ein soziales Umfeld, welches bereit ist, seine eigenen Bedürfnisse für einen längeren Zeitraum hintenan zu stellen. Oder auch Kollegen und Kolleginnen, die den entscheidenden Hinweis liefern, wenn das Brett vorm eigenen Kopf dicker als so manches Statistikbuch ist.

Ich möchte die Gelegenheit nutzen, um mich bei den Menschen zu bedanken, die all dies – und noch Einiges mehr – für mich getan haben. Meinem Doktorvater Prof. Dr. Udo Rudolph danke ich in erster Linie für die Möglichkeit, meine Promotion im Forschungsfeld der Herzratenvariabilität zu schreiben. Udo, vielen Dank für deine zahlreichen wertvollen Hinweise, für das permanente Kalibrieren meines Fokus' auf das Wesentliche, für deine Geduld und deinen Zuspruch immer dann, wenn er dringend notwendig war. Danke auch, dass du immer an mich geglaubt hast. Meinem Zweitgutachter, Prof. Dr. Josef Krems, danke ich für seine Bereitwilligkeit, meine Arbeit zu begutachten und für seine zeitliche Flexibilität im Rahmen der Disputation.

Ein außerordentlicher Dank gilt auch meinen Kollegen und Kolleginnen. Eure Unterstützung, ob aktiv bei Fragen zu meiner Promotion oder passiv, indem ihr mir den Rücken freigehalten habt, war und ist ungemein wertvoll für mich. Insbesondere danke ich André Körner, Annett Meylan, Thomas Schäfer, Chris Maiwald, Andreas David, Jasper Marahrens, Tanja Stölzel, Dieter Reichelt, Olav Schwarz, Karin Steinsdörfer und Stephanie Laux. André, dir möchte ich auch für deine großartige und freundschaftliche Unterstützung fernab des universitären Umfelds danken. Annett und Tanja, euer sorgfältiges Lesen der Monografie war mir eine große Hilfe – vielen Dank. Ein herzlicher Dank gebührt außerdem den (ehemaligen) Studierenden Sebastian Viertel, Conrad Koczielski, Sarah de Vries, Denise Schneider, Marc Urban und Nadine Winter.

Die fachliche Unterstützung im Rahmen einer so umfangreichen wissenschaftlichen Arbeit ist sicher von unschätzbarem Wert. Allerdings – und dies mag möglicherweise für mich besonders zutreffen – glaube ich, dass eine solche Arbeit ohne die Unterstützung meiner Freunde und Familie nicht möglich gewesen wäre. Christoph, Steffi, Christian, Martin, Timm, Lydia, Rene, Nils und vielen weiteren danke ich für eure Freundschaft. Für Gespräche mit und ohne Sinn, für Zuversicht, wenn ich sie dringend gebraucht habe, und für eure Aufmunterung, wenn mir eigentlich nicht danach war.

Einen großen, wenn nicht sogar den größten, Anteil an dieser Arbeit hat meine wunderbare Familie. Liebe Hannah, lieber Julius, auch wenn euch das sicher nicht bewusst ist, habt ihr einen entscheidenden Beitrag geleistet. Mit euch zu spielen, zu lachen und herumzualbern hat mich stets auf andere Gedanken gebracht. Meiner Schwester Gaby, meinem Schwager Jan, meinen Onkeln und Tanten möchte ich für den permanenten Rückhalt und Zuspruch danken. Gleiches gilt für meine „Uhlig-Oma“ und meinen Stiefvater Dirk. Meinem Vater, Joachim Uhlig, danke ich für seine wichtige Unterstützung – insbesondere in einer sehr schweren Zeit. Ich hätte gern mehr von deiner „Unbeschwertheit“ abbekommen.

Meine liebe Rösi, du hast mich gehegt und gepflegt als es am Dringendsten war. Dafür bin ich dir auf ewig dankbar. Anett und Frank, ihr seid die besten Schwiegereltern, die ich mir nur vorstellen kann. Euer Glaube an mich war stets unerschütterlich. Vor allem möchte ich euch aber zu eurer wundervollen Tochter beglückwünschen. Ich hätte mir so sehr gewünscht, dass wir diesen Moment alle gemeinsam erleben können.

Mutti, seitdem ich denken kann bist du mein sicherer Hafen. Du warst und bist immer für mich da, insbesondere dann, wenn ich es selbst nicht kann. Dass ich diese Arbeit überhaupt zu Ende

gebracht habe, geht auch zu einem großen Teil auf dein Konto (dieser Begriff ist natürlich nicht ganz zufällig gewählt).

Schließlich möchte ich mich bei der Person bedanken, die mein Leben seit vielen Jahren so unglaublich bereichert. Meine liebe Anna, ich weiß nicht genau, ob ich die richtigen Worte finde. Du hast immer alles, wirklich alles, gegeben, um mich zu unterstützen. Deine Liebe, unsere kleine Familie (W.B.M) und unsere gemeinsame Zukunft waren und sind stets meine größte Motivation – bei allem, was ich tue (oder auch nicht tue). Ich freue mich so unendlich auf die kommenden Abenteuer mit dir. Danke für deine unfassbare Kraft, danke dafür, dass du immer an meiner Seite bist – jeden Tag, jede Stunde, jede Minute, jede Sekunde. Ich hoffe, du weißt noch, was Enten so einzigartig macht. Liebe Anna, diese Arbeit ist für dich.

Preface

The present thesis consists of three manuscripts focusing research on heart rate variability from a methodological and psychological point of view. Writing a doctoral thesis is a challenging task for a number of reasons. Inter alia, due to the challenge to familiarize with laborious review processes. In this vein, two of the following studies have already been submitted to peer-reviewed journals (Chapters III and IV; for an overview, see Table 1 and List of Publications). Hence, the studies included in this monograph were originally written as manuscripts considering APA guidelines (American Psychological Association, 2010) and/or specific journal requirements. In addition, the following chapters may differ slightly with respect to linguistic style and formal aspects. Nevertheless, I tried to provide an as uniform and consistent monograph as possible. Therefore, I also included a general introduction and overall discussion of the topics addressed in my dissertation. In addition, I connected the chapters as well as possible, to support the reader in obtaining a comprehensible and coherent picture.

In doing so, I decided to deviate from the above-mentioned manuscript guidelines to ensure readability and visual appearance of this monograph. Inter alia, this includes the design of headings, text alignment, line spacing, and positioning of tables/figures. Essential standards, as citations style, reporting of statistical tests and indices, or table/figure design are largely in line with the APA specifications (6th ed.; American Psychological Association, 2010).

Although I am the sole first author of all included studies and chapters, most of the underlying investigations are a result of collaborations with my colleagues. Therefore, at the beginning of each chapter, all contributing authors are named. Furthermore, the varying use of "I" and "we" is a result of the collaboration. However, note that the affidavit enclosed within this monograph remains unaffected.

The whole monograph is written in English, exceptions are the German summary (for an English version, see Chapters I and V), the acknowledgement, the list of publications, the curriculum vitae, and the affidavit. Additional material, not included in this monograph, is available from the enclosed CD-ROM (such as questionnaires, Excel sheets) or upon request (data sets). I hope that reading this work provides new and fascinating insights into a highly interesting biopsychological area of research.

Zusammenfassung

Ein gesunder Herzschlag zeichnet sich nicht dadurch aus, dass er besonders regelmäßig ist. Vielmehr sollte ein gesunder Herzschlag, selbst in Phasen augenscheinlicher körperlicher Inaktivität, variabel sein (z.B. Appelhans & Luecken, 2006; Berntson et al., 1997; Shaffer, McCraty, & Zerr, 2014). Historisch gesehen ist dies keine völlig neue Erkenntnis – bereits in der frühen chinesischen und griechischen Medizin konnte dieses Phänomen beobachtet werden (einen schönen Überblick hierzu gibt Billman, 2011). Das Zusammenwirken der sympathischen und parasympathischen Bestandteile des autonomen Nervensystems, welches sich unter anderem in der Herzratenvariabilität (HRV) widerspiegelt, erlaubt uns nicht nur Einblicke in die physiologische Adaptionsfähigkeit, sondern auch in die psychische Flexibilität und Regulationsfähigkeit des Menschen, um so auf sich ständig ändernde Umweltanforderungen angemessen reagieren zu können (z.B. Appelhans & Luecken, 2006; Beauchaine, 2001; ChuDuc, NguyenPhan, & NguyenViet, 2013; Porges, 1995b; Quintana & Heathers, 2014; Riganello, Garbarino, & Sannita, 2012; Shaffer et al., 2014; Stein & Kleiger, 1999; Thayer & Lane, 2000). Mit ganz einfachen Worten: Die Variabilität unseres Herzschlages stellt eine Art Interface dar, welches Auskunft über das Zusammenspiel physiologischer und psychologischer Prozesse gibt.

In der vorliegenden Monografie beschäftige ich mich intensiv mit dem Thema HRV, insbesondere mit der Anwendung und Durchführung von HRV-Kurzzeitmessungen (meistens fünf Minuten) im Kontext (bio-) psychologischer Forschung. Während ich im Rahmen des ersten Kapitels eine komprimierte Einführung in die Thematik und einen Überblick über die nachfolgenden Kapitel gebe, beschäftigt sich Kapitel II mit der Frage, welche methodischen Standards für HRV-Kurzzeitmessungen derzeit vorliegen. Ausgangspunkt hierfür sind vereinzelte Hinweise (z.B. im Rahmen meta-analytischer Bestrebungen) darauf, dass die Erfassung, Darstellung und Interpretation von HRV-Messungen durch ein nicht unerhebliches Maß an Diversität

gekennzeichnet ist (z.B. de Vries, 2013; Ellis, Zhu, Koenig, Thayer, & Wang, 2015; Quintana & Heathers, 2014; Tak et al., 2009; Zahn et al., 2016). Ferner fehlen bis heute belastbare Normwerte für die gängigsten HRV-Parameter, die typischerweise in Kurzzeitmessungen berechnet werden können (vgl. Nunan, Sandercock, & Brodie, 2010). Ausgehend von diesen Beobachtungen stellen wir ein systematisches Literaturreview vor. In einem ersten Schritt haben wir aktuelle Standards zur Erhebung und Auswertung von HRV-Messungen identifiziert, auf deren Basis wir ein Klassifikationssystem zur Beurteilung von HRV-Studien erstellt haben. Nachfolgend wurden zwischen 2000 und 2013 publizierte Artikel (*N* = 457), im Hinblick auf die extrahierten methodischen Standards, überprüft. Unsere Ergebnisse legen das Vorhandensein einer beträchtlichen methodischen Heterogenität und einen Mangel an wichtigen Informationen nahe (z.B. in Bezug auf die Erhebung essentieller Kontrollvariablen oder das Berichten von HRV-Parametern), einhergehend mit der Tatsache, dass sich gängige Empfehlungen und Richtlinien (z.B. Task Force, 1996) nur partiell in der empirischen Praxis wiederfinden. Auf der Grundlage unserer Ergebnisse leiten wir Empfehlungen für weitere Forschung in diesem Bereich ab, wobei sich unsere „Checkliste" besonders an forschende Psychologen richtet. Abschließend diskutieren wir die Einschränkungen unseres Reviews und unterbreiten Vorschläge, wie sich diese - bisweilen unbefriedigende - Situation verbessern lässt.

Während unserer umfangreichen Literaturrecherche ist uns sehr schnell aufgefallen, dass HRV-Kurzzeitmessungen auf ein breites wissenschaftliches Interesse stoßen, wobei verschiedenste Konzepte und Forschungsfragen mit spezifischen HRV-Mustern in Verbindung gebracht werden (vgl. Beauchaine, 2001; Dong, 2016; Francesco et al., 2012; Makivić, Nikić, & Willis, 2013; Nunan et al., 2010; Pinna et al., 2007; Quintana & Heathers, 2014; Sammito et al., 2015; Sandercock, 2007). Darunter befinden sich sowohl eher eigenschaftsähnliche (z.B. Trait-Angst; Miu, Heilman, & Miclea, 2009; Watkins, Grossman, Krishnan, & Sherwood, 1998) als auch stark situationsabhängige Konstrukte (z.B. akute emotionale Erregung; Lackner, Weiss, Hinghofer-

Szalkay, & Papousek, 2013; Papousek, Schulter, & Premsberger, 2002). Während die beiden einflussreichsten Theorien zur HRV, die Polyvagal-Theorie (Porges, 1995b, 2001, 2007) und das Modell der neuroviszeralen Integration (Thayer & Lane, 2000, 2009), einen dispositionellen Charakter der HRV nahelegen, sind zahlreiche Einflussfaktoren bekannt, die unmittelbare Auswirkungen auf das autonome Nervensystem haben (Fatisson, Oswald, & Lalonde, 2016; Valentini & Parati, 2009). Demzufolge haben wir uns die Frage gestellt, wie zeitlich stabil individuelle HRV-Messungen sind (siehe Kapitel III). Da die existierende Literatur hierzu ambivalente Ergebnisse bereithält (Sandercock, 2007; Sandercock, Bromley, & Brodie, 2005) und die zeitliche Stabilität von HRV-Messungen bisher vornehmlich über sehr kurze Zeiträume mit wenigen Messzeitpunkten untersucht wurde (z.B. Cipryan & Litschmannova, 2013; Maestri et al., 2009; Pinna et al., 2007), haben wir eine längsschnittliche Studie mit fünf Messzeitpunkten, verteilt auf ein Jahr, konstruiert (N = 103 Studierende). In Abhängigkeit von der Körperhaltung der Probanden während der Messung (liegend, sitzend, stehend), haben wir nachfolgend die Retest-Reliabilität (absolute und relative Reliabilität; siehe Atkinson & Nevill, 1998; Baumgartner, 1989; Weir, 2005) der gängigsten HRV-Parameter ermittelt. Unsere Ergebnisse deuten auf ein beachtliches Ausmaß an Zufallsschwankungen der HRV-Parameter hin, welches weitgehend unabhängig von der Körperhaltung der Probanden und dem zeitlichen Abstand der Messzeitpunkte ist. Da diese Ergebnisse weitreichende Folgen suggerieren, diskutieren wir diese, unter Berücksichtigung vorhandener Einschränkungen, ausführlich.

Während in Kapitel II und III vornehmlich methodische Fragen im Fokus stehen, stelle ich in Kapitel IV dieser Monografie eine Feldstudie vor. Im Rahmen dieser Studie haben wir die Zusammenhänge zwischen subjektivem Stress, Coping-Strategien, HRV und Schulleistung untersucht. Sowohl die bereits erwähnten Theorien (Porges, 1995b, 2001, 2007, Thayer & Lane, 2000, 2009), als auch eine beträchtliche Anzahl an Forschung, lassen Zusammenhänge zwischen HRV und Stress (z.B. Berntson & Cacioppo, 2004; Chandola, Heraclides, & Kumari, 2010; Krohne, 2017; Michels, Sioen, et al., 2013; Oken, Chamine, & Wakeland, 2015; Porges, 1995a; Pumprla, Howorka, Groves, Chester, & Nolan, 2002) sowie HRV und kognitiver Leistung vermuten (z.B. Duschek, Muckenthaler, Werner, & Reyes del Paso, 2009; Hansen, Johnsen, & Thayer, 2003; Luque-Casado, Perales, Cárdenas, & Sanabria, 2016; Shah et al., 2011). Allerdings fehlt es bislang an Studien, welche die komplexeren Zusammenhänge zwischen all den genannten Konstrukten untersuchen. Dies gilt insbesondere für die Untersuchung von Kindern und Jugendlichen. Um zur Schließung dieser Wissenslücke beizutragen, haben wir Gymnasiasten (N = 72, zwischen zehn und 15 Jahren alt) im Rahmen eine Querschnittstudie zu deren Stresserleben und Bewältigungsstrategien (mittels SSKJ 3-8; Lohaus, Eschenbeck, Kohlmann, & Klein-Heßling, 2006) befragt. Außerdem wurden bei all diesen Schülern HRV und Zeugnisdurchschnittsnoten erhoben. Unsere Ergebnisse unterstreichen die Bedeutung konstruktiver Coping-Strategien zur Vermeidung von physischen und psychischen Stresssymptomen, welche ihrerseits negative Auswirkungen auf die Schulleistung haben. Demgegenüber lassen sich die erwarteten Zusammenhänge zwischen HRV und Stress/Coping (Berntson & Cacioppo, 2004; Dishman et al., 2000; Fabes & Eisenberg, 1997; Lucini, Di Fede, Parati, & Pagani, 2005; Michels, Sioen, et al., 2013; O'Connor, Allen, & Kaszniak, 2002; Porges, 1995a) sowie HRV und kognitiver Leistung (Hansen et al., 2003; Suess, Porges, & Plude, 1994; Thayer, Hansen, Saus-Rose, & Johnsen, 2009) anhand unserer Daten nicht bestätigen. Mögliche Gründe für dieses Befundmuster sowie Anforderungen an zukünftige Studien dieser Art werden abschließend diskutiert.

Schlussendlich (a) fasse ich alle gesammelten Erkenntnisse prägnant zusammen, (b) diskutiere deren Implikationen, (c) stelle deren Beitrag zum wissenschaftlichen Forschungsstand heraus, und (d) gebe einen kurzen Einblick in die jüngsten Entwicklungen der HRV-Forschung (Kapitel V). Außerdem, und damit schließe ich den inhaltlichen Part dieser Monografie ab, möchte ich den Leser an meinen zehn wichtigsten Lernerfahrungen teilhaben lassen.

List of Contents

List of Tables

List of Figures

Abbreviations

ACTH	adrenocorticotropic hormone
ANS	autonomic nervous system
AR	Autoregressive Algorithm
BMI	body mass index
cpd 2y	impact factor: cites per document in the previous two years
CAN	central autonomic network
CRH	corticotropin-releasing hormone
CV	coefficient of variation of interbeat intervals
CV%	coefficient of variation
ECG	electrocardiogram
GPA	grade point average
FFT	Fast Fourier Transform
HF	high frequency power
HF nu	normalized units of high frequency power
HPA	hypothalamus-pituitary-adrenal axis
HR	heart rate
HRV	heart rate variability
IBI	interbeat interval
ICC	intraclass correlation coefficient
LF	low frequency power
LF nu	normalized units of low frequency power
LF/HF	ratio of low frequency and high frequency power
ln	natural logarithm
NN50	number of successive interbeat intervals that differ by more than 50 ms
NN interval	normal-to-normal interval
pNN50	percentage of successive interbeat intervals with a difference > 50 ms

PNS	parasympathetic nervous system
PPG	photoplethysmograph
PSD	power spectral density
rMSSD	square root of the mean squared differences of consecutive IBIs
RSA	respiratory sinus arrhythmia
SAM	sympathetic adrenomedullary axis
SDNN	standard deviation of the interbeat intervals
SEM	standard error of measurement
SJR	impact factor: SCImago Journal Rank
SNS	sympathetic nervous system
SRD	smallest real difference
TFG	Task Force guidelines
TP	total power
VLF	very low frequency power

Chapter I

1. An Introduction into Heart Rate Variability and My Past Five Years of Research

When I started to deal in depth with *heart rate variability* (HRV) about five years ago, I was very fascinated about the possibility to attain objective insights about the interface between physiological and psychological processes, and this enthusiasm is still present. Nevertheless, I had to realize that HRV research is a highly complex subject matter, requiring not only psychological, but also detailed physiological, medical, technological, and mathematical understanding. In this respect, the following introduction has two goals: (a) I would like to equip the reader with basic knowledge on HRV, and (b) I will give a comprehensive overview regarding my studies within this area.

Psychological research on HRV received increasing attention during the last two decades (e.g., Beauchaine, 2001; de Vries, 2013; Quintana & Heathers, 2014). When analysing the relevant database entries between 1996 and 2016, it becomes apparent that this trend is evident both in medicine and psychology. In MEDLINE, representing predominantly medical research, new entries per year have approximately quadrupled between 1996 and 2016 (from 312 new entries in 1996 up to 1,141 in 2016). In PsycINFO and for the same time interval, the number of new entries per year involving HRV studies has increased by a factor of about 18 (from 20 new entries in 1996 up to 358 new entries in 2016; search term: *heart rate variability*). Figure 1 illustrates these trends for the past 20 years. Therefore, it becomes evident that HRV has become an important concept in both medicine and psychology (see also Berntson et al., 1997; Eller-Berndl, 2015; Riganello et al., 2012; Shaffer et al., 2014; Stein & Kleiger, 1999). This broad application of HRV measurements is also evident in other scientific disciplines (e.g., sport and occupational science) as well as in clinical practice (Dong, 2016; Francesco et al., 2012; Makivić et al., 2013; Nunan et al., 2010;

Pinna et al., 2007; Sammito et al., 2015; Sandercock, 2007). In this vein, many researchers regard HRV as an objective, economic and non-invasive methodology at the interplay between physical and psychological processes (Berntson et al., 1997; Guo & Stein, 2002; Quintana & Heathers, 2014; Riganello et al., 2012; Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012). In principle, short-term (usually five minutes) and long-term measurements (usually periods of 24 hours) of HRV are usually distinguished within the literature (e.g., see Kleiger, Stein, & Bigger, 2005; Laborde, Mosley, & Thayer, 2017; Sammito et al., 2015; Task Force, 1996; Thayer et al., 2012). Due to their relevance for psychological research, this thesis focuses on short-term measurements of HRV.

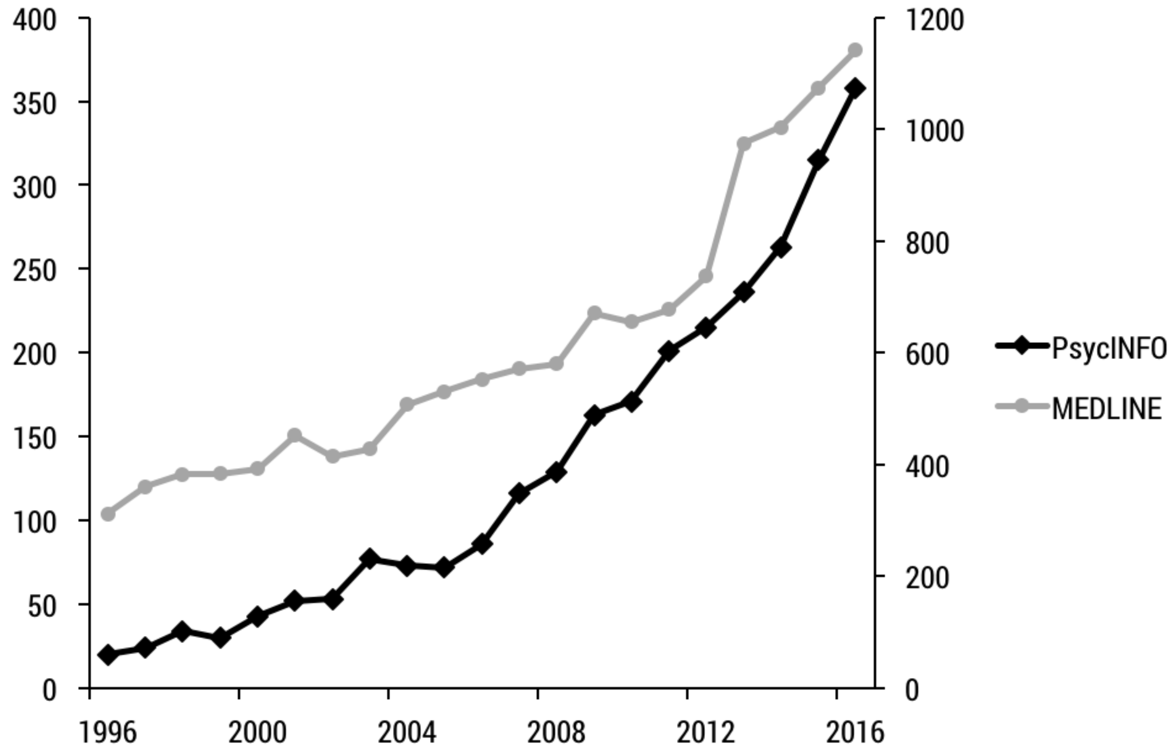


Figure 1. Number of new database entries within the relevant year for the search term heart rate variability between 1996 and 2016. Primary axis relates to PsycINFO database, secondary axis to MEDLINE. The proportional increase for PsycINFO is considerably steeper.

1.1. Meaning of HRV

Even under conditions of rest, the temporal distances of successive heartbeats are subject to fluctuations, forming the basis of HRV measurements (Appelhans & Luecken, 2006; Kemp & Quintana, 2013; Stein & Kleiger, 1999; Thayer et al., 2012). Within a complex environment, the human organism is persistently exposed to highly dynamic situational demands and rapidly changing social interactions. In this regard, HRV can be considered as the human organism's ability to cope with and adapt to continuous situational requirements, both physiologically and emotionally (see also Beauchaine, 2001; McCraty, Atkinson, Tiller, Rein, & Watkins, 1995; Quintana & Heathers, 2014; Shaffer et al., 2014; Thayer & Lane, 2000). In general, individuals, characterized by highly variable heart rates, are deemed as healthy organisms, well able to cope with situational demands, while low HRV points to adaptive and health-related complications (for overviews, see Appelhans & Luecken, 2006; Beauchaine, 2001; Beauchaine & Thayer, 2015; Cygankiewicz & Zareba, 2013; Pumprla et al., 2002; Riganello et al., 2012; Shaffer et al., 2014; Stein & Kleiger, 1999). Therefore, flexibility of *interbeat intervals*[1] (IBI) is seen as an important indicator and predictor of both physical and mental health: Epidemiological data suggest that low HRV seems to be, inter alia, a risk factor (or symptom) with respect to neurological (e.g., epilepsy; Lotufo, Valiengo, Benseñor, & Brunoni, 2012; Tomson, Ericson, Ihrman, & Lindblad, 1998), cardiovascular (e.g., hypertension; Huikuri et al., 1996; Schroeder et al., 2003), and mental disorders (e.g., depression; Carney et al., 2001; Kemp et al., 2010; Kemp, Quintana, Felmingham, Matthews, & Jelinek, 2012), as well as with mortality (for overviews and details, see Beauchaine, 2001; Beauchaine & Thayer, 2015; Cygankiewicz & Zareba, 2013; de Vries, 2013; Hoyer, 2009; La Rovere et al., 2003; Pumprla et al., 2002; Riganello et al., 2012; Shaffer et al., 2014; Stein & Kleiger, 1999; Thayer & Lane, 2007; Tsuji et al., 1994). In addition, existing empirical evidence

[1] Note that I use the terms interbeat interval (i.e., temporal intervals between successive heartbeats; Appelhans & Luecken, 2006), beat-to-beat interval, and normal-to-normal interval (NN interval) interchangeably.

associates autonomic modulation and thus HRV with emotional/social competences (e.g., Appelhans & Luecken, 2006; Eisenberg et al., 1995; Hastings et al., 2008), occupational stress (e.g., Chandola et al., 2010; Jarczok et al., 2013), or cognitive performance (e.g., Hansen et al., 2003; Suess et al., 1994; Thayer et al., 2009).

1.2. A Brief Historical Overview of HRV Research

Interest into the variability of heart rate is not new, and has been closely connected to pulse (rate) research. Therefore, some brief historical remarks are helpful here (for a comprehensive overview, see Billman, 2011).

The oldest available written notes on heart rhythm were provided by the Greek physician and scientist Herophilus (ca. 335-280 BC; Bedford, 1951). Luckily, some of his insights have been transmitted by Galen of Pergamum (131-200 AD). Galen wrote about 18 books and approximately eight essays on pulse research, introducing the diagnostic and prognostic potential of pulse measurements (Bedford, 1951; Billman, 2011). Furthermore, in early Chinese medicine, Bian Que (about 500 BC) is known as one of the first physicians who analysed the human pulse (see also Ernst, 2014). The Chinese physician Wang Shu-Ho (180-270 AD) also noted that an overly uniform heartbeat is associated with negative effects, such as mortality (Eller-Berndl, 2015).

In the 18th century, Stephen Hales (1677-1761) documented the periodic fluctuations in the beat-to-beat interval and the interplay between pulse and respiration (Billman, 2011; Eller-Berndl, 2015; Ernst, 2014; Hales, 1733). A more detailed description of respiratory influences on heart rate was given by the German physiologist Carl Ludwig (1816-1895) by using an instrument called kymograph (Billman, 2011; Eller-Berndl, 2015; Ernst, 2014; Ludwig, 1847). Nowadays, this phenomenon is better known as *respiratory sinus arrhythmia* (RSA): A heart rate acceleration is apparent during inhalation, while exhalation causes a decrease of heart rate (see also Appelhans

& Luecken, 2006; Berntson et al., 1997; Berntson, Cacioppo, & Quigley, 1993; Grossman & Taylor, 2007; Shaffer et al., 2014).

Additional important insights have been made during the past five decades. In the 1960ies, it became possible to capture changes in IBIs over longer time periods, as electrocardiogram (ECG) technology advanced (Billman, 2011). A major advance has been the development of portable devices (see Holter, 1961). Hon and Lee (inter alia 1963) demonstrated the enormous clinical relevance of HRV in studies on the development of fetal HRV. Further milestones were new methods and algorithms for digital signal processing (e.g., Billman, 2011; Cooley & Tukey, 1965; Jenkins & Watts, 1968; Kamath, Watanabe, & Upton, 2012) and the application of power spectrum analysis for physiological explorations (e.g., Akselrod et al., 1981; Billman, 2011; Chess, Tam, & Calaresu, 1975; Hyndman, Kitney, & Sayers, 1971; Penáz, Honzíková, & Fiser, 1978; Sayers, 1973). As a result, *frequency domain parameters* (e.g., Akselrod et al., 1981) and *time domain parameters* (e.g., Kleiger, Miller, Bigger, & Moss, 1987) were established (Ernst, 2014; Kamath et al., 2012). The analysis of nonlinear characteristics of HRV was mainly inspired by research of Goldberger and colleagues (see Goldberger, 1990; Goldberger, Findley, Blackburn, & Mandell, 1984; Goldberger & West, 1987). Moreover, Axelrod and colleagues (1987) introduced short-term recordings of HRV, and their usefulness has been demonstrated shortly afterwards (e.g., by Bigger, Fleiss, Rolnitzky, & Steinman, 1993).

Eventually, the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (referred to as Task Force) provided standardized guidelines for HRV measurements, their interpretation, and their application (referred to as TFG below; Task Force, 1996). Despite recent attempts to update the TFG or to provide additional recommendations (e.g., by Laborde et al., 2017; Quintana, Alvares, & Heathers, 2016), these standards are still valid today.

1.3. Physiological Underpinnings and Influences on HRV

As mentioned, the human heart rate is subject to permanent variations. Therefore, let me briefly summarize some physiological basics. Although it is well-known that a large number of factors exert influences on heart rate and HRV (Appelhans & Luecken, 2006; Fatisson et al., 2016; Thayer, 2007), the subsequent explanations focus on efferent regulatory effects by the *autonomic nervous system* (ANS; also called vegetative nervous system; Eller-Berndl, 2015; Schandry, 2016). At this point, the interested reader is referred to further literature dealing with regulatory and control functions of the *central autonomic network* (CAN), involved cortical structures, as well as the afferent connections between heart and brain (e.g., see Appelhans & Luecken, 2006; Benarroch, 1993; de Vries, 2013; Kemp & Quintana, 2013; Pinel & Pauli, 2017; Riganello et al., 2012; Shaffer et al., 2014; Thayer, 2007; Thayer et al., 2012; Thayer & Lane, 2000).

The ANS is a subunit of the peripheral nervous system, which is in turn controlled by the CAN (Appelhans & Luecken, 2006; Benarroch, 1993; Pinel & Pauli, 2017; Riganello et al., 2012; Thayer, 2007). Both efferent parts of the ANS, the *sympathetic nervous system* (SNS) and the *parasympathetic nervous system* (PNS), exert influence on the activity of the *sinoatrial node* and the atrioventricular node (the hearts' pacemakers), and therefore modulate the heart rate (additionally, see Berntson et al., 1997; Eller-Berndl, 2015; Hoyer, 2009; Shaffer et al., 2014). By influencing the sinostrial node, the SNS has an excitatory effect on heart rate (based on effects of norepinephrine), while the PNS exerts an inhibitory effect (based on effects of the vagal nerve and acetylcholine-transmission; Appelhans & Luecken, 2006; Eller-Berndl, 2015; Shaffer et al., 2014). Note that the PNS effect is a considerably faster process. Hence, vagal modulation exerts stronger short-term effects (see also Berntson et al., 1997; Kemp & Quintana, 2013; Nunan et al., 2010; Pumprla et al., 2002). As the intrinsic activity of the sinostrial node is considerably higher (up to about 100 potentials per minute) as compared to the age-depending resting heart rate (e.g., see Fleming et al., 2011), the PNS permanently downregulate the heart rate under rest (Appelhans & Luecken, 2006; Berntson et al., 1997; Cygankiewicz & Zareba, 2013; Eller-Berndl, 2015; Jose & Collison, 1970; Opthof, 2000; Shaffer et al., 2014; Thayer et al., 2012). Hence, the resulting heart rate variations (i.e., HRV) shed light on the flexibility and functional capability of the ANS (see also Hoyer, 2009; Malik & Camm, 1990; Pumprla et al., 2002; Stein & Kleiger, 1999; Task Force, 1996). Thus, it is not surprising that HRV measurements, allowing for comparatively easy insights into autonomic modulation, are of broad scientific interest.

However, researchers should be aware of a large body of additional influences on HRV, such as circadian rhythms (e.g., see Bilan, Witczak, Palusiński, Myśliński, & Hanzlik, 2005; Guo & Stein, 2002), age (Agelink et al., 2001; Antelmi et al., 2004; Voss, Schroeder, Heitmann, Peters, & Perz, 2015), or subjects' posture during measurement (e.g., Acharya, Kannathal, Lee, & Leong, 2005; Radhakrishna, Dutt, & Yeragani, 2000; Young & Leicht, 2011). Moreover, note that the various number of influence factors are also likely to interact with each other (for an overview, see Fatisson et al., 2016). In this vein, HRV measurements are not as simple as they may appear at first glance. A detailed debate of this state of affairs is subject of Chapter II.

1.4. Theories of HRV

There are at least a handful theories dominating HRV research in the past (for comprehensive overviews, see Laborde et al., 2017; Shaffer et al., 2014), while two of them are worth-mentioning at this point very briefly - these are: The *polyvagal theory* by Stephen Porges (1995b, 2001, 2007) and the *model of neurovisceral integration* by Julian Thayer and Richard Lane (2000, 2009).

The polyvagal theory (Porges, 1995b, 2001, 2007), an essentially evolutionary and phylogenetic approach, regards the human ability of self-regulation in order to be successful within social situations as a result of various adaptive developmental stages of the ANS:

(1) A very simple and therefore original form of regulation occurs through an unmyelinated part of the vagus, the so-called *dorsal vagal complex*, arising in the dorsal motor nucleus and caused the individual to freeze in case of danger.

(2) On the basis of SNS activity, individuals were able to mobilize energy reserves (e.g., by accelerating heart rate) to counter threats with the well-known fight-flight-response.

(3) The myelinated part of the vagus, mainly immanent to mammals and thus humans, is called the *ventral vagal complex* and has its origin in the nucleus ambiguus. Above all, this component allows the organism for fast down-regulation and inhibition (as a kind of "vagal brake"), especially important within highly dynamic social interactions.

However, Porges not only emphasizes the efferent mechanisms of human regulation, but also points to the multitude of afferent pathways between vagus and brain. Finally, the theory suggests that RSA measurement (as assessed by HRV) provides information about individual regulatory and adaptive capacity – on a physiological (e.g., heart rate adjustment by ventral vagus) as well as on a psychological (e.g., emotion regulation) level. To put it in the words of Porges: "Functionally, the vagal brake, by modulating visceral state, enables the individual to rapidly engage and disengage with objects and other individuals and to promote self-soothing behaviors and calm states" (Porges, 2007, p. 121). Eventually, it is worth-mentioning that the polyvagal theory has been also subject to criticism (above all, see Grossman & Taylor, 2007).

Porges' theory is supplemented by the model of neurovisceral integration. The dynamic system approach by Thayer and Lane (2000, 2009) emphasizes the central role of the CAN, since it acts as a control unit or command centre between higher cerebral structures (e.g., anterior cingulate cortex, prefrontal cortex, nuclei of amygdala and hypothalamus, insula, nucleus ambiguus) and the ANS (with efferent and afferent pathways, see also Appelhans & Luecken, 2006; Benarroch, 1993). From a functional point of view, the human adaptability and self-regulatory capacity depend, inter alia, on the abilities of goal-oriented attentional control and emotion regulation (Heilman, 1997; Thayer & Lane, 2000). Due to the associations mentioned above, the influences of the peripheral structures on the heart provide insights into humans' adaptability and regulatory capacity. Thus, HRV can be regarded as direct indicator of the (non-) functioning of central nervous system structures and their interplay with the peripheral ANS (see also Friedman & Thayer, 1998). In my opinion, these complex relationships are best summarized by Appelhans and Luecken (2006, p. 231): "Therefore, HRV reflects the moment-to-moment output of the CAN and, by proxy, an individual's capacity to generate regulated physiological responses in the context of emotional expression (Thayer & Lane, 2000; Thayer & Siegle, 2002)." In order to deepen and expand the model, subsequent research focused on associations between vagal tone and human adaptability as well as cognitive performance (e.g., Hansen et al., 2003; Hansen, Johnsen, & Thayer, 2009; Lane et al., 2009; Thayer et al., 2012; Thayer & Lane, 2007).

To summarize: Both theories are in conformity regarding the primary importance of PNS activity (or inactivity) in the context of emotional and physiological regulation. Moreover, HRV measurements are seen as suitable indices shedding light on these regulatory processes (Appelhans & Luecken, 2006). Finally, it is worth-mentioning that both theories do not exclude each other, but rather should be considered as complementary.

1.5. HRV Measurement: From Heartbeat to HRV Parameters

To continuously record the IBIs of the heart rate, typically an ECG or a photoplethysmograph (PPG) is used. Higher accuracy is provided by ECG measurements (Appelhans & Luecken, 2006; Berntson et al., 1997; Charlot, Cornolo, Brugniaux, Richalet, & Pichon, 2009; Eller-Berndl, 2015; Schäfer & Vagedes, 2013; Shaffer et al., 2014; Task Force, 1996). Figure 2 illustrates a short series of IBIs with different temporal distances. After recording, different options for data processing and data analyses are available. The assessment of HRV can be based on several kinds of parameters: These refer to (a) observations across time intervals (time domain parameters), (b) observations of frequencies (frequency domain parameters), and (c) quite complex *nonlinear techniques* (e.g., see Allen, Chambers, & Towers, 2007; Appelhans & Luecken, 2006; Cygankiewicz & Zareba, 2013; Kleiger et al., 2005; Sassi et al., 2015; Shaffer et al., 2014; Stein & Kleiger, 1999; Task Force, 1996). Note that options for data analyses will also depend upon recording time (short-term measurement vs. long-term measurement). As mentioned above, we focus on short-term measurements. In what follows, we briefly summarize the most common time domain and frequency domain parameters. Further information on nonlinear procedures are outlined in Chapter II.

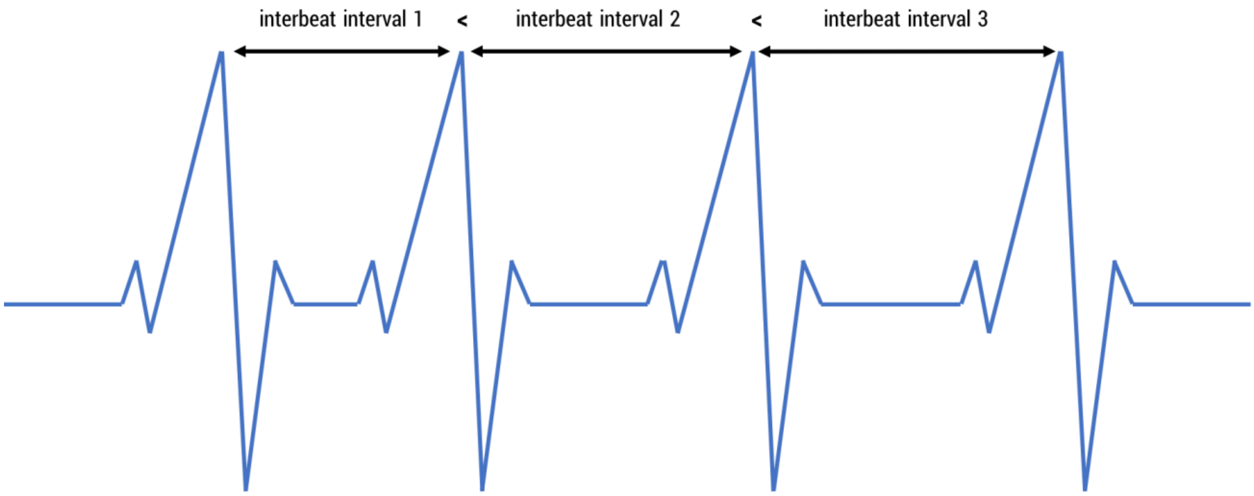


Figure 2. Schematic representation of successive interbeat intervals of different lengths.

1.5.1. Time Domain Analyses

Time domain parameters are based on descriptive statistical analyses of a certain number of (consecutive) IBIs (Appelhans & Luecken, 2006; Berntson et al., 1997; Eller-Berndl, 2015; Shaffer et al., 2014; Stein & Kleiger, 1999). In this vein, the following parameters are regarded as suitable for short-term recordings:

The standard deviation of IBIs (*SDNN*, in ms) is a global index of overall variability and strongly depends on the length of the analysis interval (e.g., see Allen et al., 2007; Appelhans & Luecken, 2006; de Vries, 2013; Eller-Berndl, 2015; Laborde et al., 2017; Nunan et al., 2010; Shaffer et al., 2014; Task Force, 1996). The square root of the mean squared differences of consecutive IBIs (*rMSSD*, in ms) is regarded as a suitable measure of PNS influences (e.g., Appelhans & Luecken, 2006; Cygankiewicz & Zareba, 2013; Eller-Berndl, 2015; Hoyer, 2009; Task Force, 1996). *NN50* is the number of successive IBIs differing by more than 50 ms, while *pNN50* (in %) represents the percentage of NN50 IBIs. Again, this measure is often seen as an indicator of PNS activity (Allen et al., 2007; Appelhans & Luecken, 2006; Cygankiewicz & Zareba, 2013; Eller-Berndl, 2015; Kleiger et al., 2005; Nunan et al., 2010; Task Force, 1996).

1.5.2. Frequency Domain Analyses

As compared to time domain analyses, calculation of frequency domain parameters is more complex. In general, these are determined by using a *frequency band analysis* (also power spectral density analysis; Shaffer et al., 2014), splitting the signal into its different periodic components (so called spectral components or frequency bands; see Appelhans & Luecken, 2006; Berntson et al., 1997; Cygankiewicz & Zareba, 2013; de Vries, 2013). The resulting power density spectrum permits conclusions regarding the impact of different physiological rhythms on HRV, especially respiratory influences (see also Allen et al., 2007; Eller-Berndl, 2015; Pumprla et al., 2002; Shaffer et al., 2014). In sum, spectral analyses yield the following parameters suitable for short-term measurements:

The *high frequency power* (HF, in ms^2, 0.15 to 0.40 Hz) is seen as an direct indicator of vagal (parasympathetic) modulation of the heart, thus reflecting respiratory influences (Appelhans & Luecken, 2006; de Vries, 2013; Eller-Berndl, 2015; Pumprla et al., 2002; Task Force, 1996). Hence, this parameter is sometimes referred to as respiratory band (Shaffer et al., 2014) or RSA (Allen et al., 2007; Berntson et al., 1997). The *low frequency power* (LF, in ms^2) is commonly observed within a range of 0.04 to 0.15 Hz (Appelhans & Luecken, 2006; Cygankiewicz & Zareba, 2013; Task Force, 1996) and might be due to both, PNS and SNS activity (Berntson et al., 1997; Laborde et al., 2017). Additionally, the LF band is also likely to represent baroreceptor activity (Eller-Berndl, 2015; Goldstein, Bentho, Park, & Sharabi, 2011; Shaffer et al., 2014). As the interpretation of the *very low frequency power* (VLF, in ms^2, 0.003 to 0.04 Hz) is not recommended for short-term measurements (≤ five minutes; Task Force, 1996), I do not go into more detail at this point (for more information, see Berntson et al., 1997; Shaffer et al., 2014). Regarding the previous remarks on LF and its controversial physiological background, the initial description of the *LF to HF ratio* (LF/HF) as index of sympathovagal balance (as proposed by Malliani, Pagani, Lombardi, & Cerutti, 1991; Pagani et al., 1984, 1986) has been rejected for several reasons (see Berntson et al., 1997; Billman, 2013; Eckberg, 1997; Heathers, 2014; Shaffer et al., 2014). Finally, the *total power* (TP), computed as the sum of HF, LF, and VLF (Burr, 2007), is regarded as a measure of overall variability (de Vries, 2013; Eller-Berndl, 2015; Kleiger et al., 2005; Sammito & Böckelmann, 2015).

1.6. Overview of Chapters Included in this Monograph

So far, I provided some basic information on HRV. My goal has been to present a brief overview of this fast-growing field of research. I will now outline my main research questions.

1.6.1. Short-Term HRV: Theoretical Standards versus Empirical Reality

After having intensively studied the theoretical basics of HRV at the beginning of my PhD project, I became more and more interested in the "how to" of HRV measurements within a psychological context. However, based on a bachelor thesis by Sarah de Vries (2013), and despite the fact that universal standards for HRV measurements had been available since 1996 (Task Force, 1996), we realized quickly that the existing literature regarding the application, implementation, and interpretation of short-term HRV measurements is quite diverse. Moreover, despite its increasing popularity (e.g., Beauchaine, 2001; de Vries, 2013; Quintana & Heathers, 2014), generally accepted and robust standard values for short-term HRV are still not available (Nunan et al., 2010), although these are urgently required. One reason for this unsatisfying state of affairs might be the limited comparability of HRV studies (e.g., see de Vries, 2013; Ellis et al., 2015; Quintana & Heathers, 2014; Tak et al., 2009; Zahn et al., 2016). In addition, the exact methodological status quo of HRV short-term measurements has not yet been well-documented. In what follows, we designed a review to quantify the extent of methodological heterogeneity: In this vein, we conducted a comprehensive literature research to identify the Task Force standards in detail and to supplement them with more recent findings. Subsequently, by means of a systematic literature review, we analysed *N* = 457 psychological studies published between 2000 and 2013. Using an in-house developed classification system, we investigated the studies' conformity with established methodological criteria. Finally, based on our findings, we derived recommendations and proposals for future research on short-term HRV (see Chapter II).

1.6.2. Short-Term HRV: Reliability versus Variability

During our extensive literature research, we realized that HRV short-term measurements are of broad scientific interest and related to a multitude of research questions and concepts (e.g., see Beauchaine, 2001; Berntson et al., 1997; Dong, 2016; Francesco et al., 2012; Makivić et al., 2013; Nunan et al., 2010; Pinna et al., 2007; Quintana & Heathers, 2014; Sammito et al., 2015; Sandercock, 2007; Stein & Kleiger, 1999). However, when considering the existing literature, HRV seems to be associated with almost "all possible" physiological and psychological concepts. Some of these reflect situational variables (e.g., acute emotional arousal; Lackner et al., 2013; Papousek et al., 2002), while others are apparently of an enduring kind (e.g., trait-anxiety; Miu et al., 2009; Watkins et al., 1998). This has led me to my next question, which again is of methodical nature: To which extent reflect HRV measurements individual dispositions rather than situational influences? In other words: Are short-term HRV measurements retest-reliable and stable across time? The existing evidence in this regard revealed that test-retest reliability of HRV measurements is far from clear (e.g., Sandercock, 2007; Sandercock et al., 2005). Furthermore, reliability studies using longer time intervals between test and retest (> two months) as well as multiple retests were largely missing.

In my view, the two influential theories described above (i.e., the polyvagal theory and the model of neurovisceral integration; Porges, 1995b, 2001, 2007, Thayer & Lane, 2000, 2009) suggest a considerable amount of trait variance. On the downside, there are numerous situational factors with well-known influences on the ANS and thus HRV (for overviews, see Chapter II as well as Fatisson et al., 2016; Valentini & Parati, 2009). To pursue this issue, we designed a study with five repeated measurements per subject across one year (*N* = 103), to analyse test-retest-reliabilities of HRV measurements depending on the time interval between measurements and depending on subjects' posture (supine, sitting, standing). To attain in-depth insights into reliability of HRV measurements, we investigated relative reliability as well as absolute reliability of the most common HRV parameters (Atkinson & Nevill, 1998; Baumgartner, 1989; Hallman, Srinivasan, & Mathiassen, 2015; Maestri et al., 2009; Pinna et al., 2007; Weir, 2005). More details including results and conclusions are presented in Chapter III.

1.6.3. HRV: A Trustworthy Indicator of Pupils' Stress, Coping, and School Achievement?

Finally, after addressing these methodological questions, I will present a field study investigating whether HRV measurements are indicators of self-reported stress, coping strategies, and school performance. Based on the theories of Porges (1995b, 2001, 2007) and Thayer and Lane (2000, 2009), we might expect associations between HRV and self-regulation as well as HRV and cognitive performance. Moreover, the relationships between HRV and different kinds of stress have been investigated intensively in recent years (above all Berntson & Cacioppo, 2004; Chandola et al., 2010; Krohne, 2017; Michels, Sioen, et al., 2013; Oken et al., 2015; Porges, 1995a; Pumprla et al., 2002). The same applies to the association between HRV and cognitive performance (e.g., see Duschek et al., 2009; Hansen et al., 2003; Luque-Casado et al., 2016; Shah et al., 2011). However, studies analysing the more complex relationships between self-reported stress, coping, HRV, and school achievement (as a more general indicator of cognitive performance) are largely absent. For this purpose, we conducted a cross-sectional study within an educational context (*N* = 72, high school students aged between ten and 15 years). We investigated pupils’ stress and coping strategies by means of a questionnaire (SSKJ 3-8; Lohaus et al., 2006), recorded their HRV under resting conditions, and collected pupils’ grade point averages as indicators of school achievement. Our results and their discussion with respect to current empirical evidence are presented in Chapter IV.

In this vein, Table 1 gives a brief overview of studies that are subject to the next chapters. Within the final section of this monograph (Chapter V), I will provide an overall discussion of the results of these studies. Within this discussion, I will outline conclusions concerning potential future directions of HRV research. In addition, I will give an overview of the ten most important learning experiences of my research on heart rate variability ("lessons I have learned so far").

Table 1

Overview of Studies Included in this Monograph

Study	Research Question(s)	Final Sample	Study Design	Theses Involved	State of Publication[a]
Chapter II: A Systematic Review of Short-Term Heart Rate Variability in Psychological Research: Toward Unified Methodological Standards	(1) What is the methodological status quo when assessing HRV in humans? (2) Are there uniform measurement standards? (3) To what extent do previous studies consider the TFG of 1996? (4) Which best practice criteria can be derived from the findings?	*N* = 457 articles indexed in PsycINFO	Systematic Literature Review	de Vries, (2013) Schneider (2015)	In preparation for submission[b]
Chapter III: Reliability of Short-Term Measurements of Heart Rate Variability: Findings from a Longitudinal Study	(1) Are measurements of HRV retest-reliable at all? (2) To what extend vary HRV measurements within individuals? (3) Are situational influences on HRV underestimated?	*N* = 103, healthy students, Mean Age: 21.72 ± 3.31 years	Longitudinal Study over a period of one year	--	Submitted for publication (appeal against rejection pending)[c]
Chapter IV: Stress and Coping in School: Heart Rate Variability, Self-Reported Stress, and School Achievement	(1) Is HRV a useful indicator of self-reported coping and stress symptoms? (2) Is HRV an indicator of school achievement? (3) What predicts pupils' school achievement and stress symptoms best?	*N* = 72, high school students, Mean Age: 12.65 ± 1.21 years	Cross-sectional Study	Winter (2016)	Submitted for publication[d]

Notes. HRV = heart rate variability, TFG = Task Force guidelines.

[a]Date: November, 24th, 2017.

[b]Uhlig, S., Meylan, A., & Rudolph, U. (2017). *A systematic review of short-term heart rate variability in psychological research: Toward unified methodological standards*. Manuscript in preparation.

[c]Uhlig, S., Meylan, A., & Rudolph, U. (2017). *Reliability of short-term measurements of heart rate variability: Findings from a longitudinal study*. Manuscript submitted for publication.

[d]Uhlig, S., Winter, N., Meylan, A., & Rudolph, U. (2017). *Stress and coping in school: Heart rate variability, self-reported stress, school achievement*. Manuscript submitted for publication.

Chapter II

2. A Systematic Review of Short-Term Heart Rate Variability in Psychological Research

Toward Unified Methodological Standards

Uhlig, S.[1], Meylan, A.[1], & Rudolph, U.[1]

[1]*Chemnitz University of Technology, General Psychology and Biopsychology*

Abstract

Research on heart rate variability (HRV) enjoys increasing popularity in psychology. The Task Force guidelines (TFG) published in 1996 aimed to providing standards for measurement and interpretation of HRV. Based on a systematic literature review, we investigated the application of these requirements in 457 psychological studies published between 2000 and 2013. We focused on HRV studies employing short-term HRV measurements in humans. Our results reveal a remarkable methodological diversity - especially with respect to important aspects of measurement (e.g., data recording and analyses, posture of subjects) and presentation of results in terms of reported time and frequency domain parameters. In addition, the percentage of studies, which do not report important information, is large. By and large, studies referring to the TFG conform to these guidelines to a higher degree. However, there are new developments in HRV research, requiring an update and extension of the already existing Task Force standards. Finally, we discuss potential reasons for the present heterogeneity in HRV research, make proposals to improve this situation, and outline recommendations for future research.

Keywords: heart rate variability, systematic review, standards, Task Force, short-term measurement, status quo, recommendations

2.1. Introduction

As briefly outlined in Chapter I, heart rate variability (HRV) in humans is subject to broad scientific interest, with a special focus on the interrelations between short-term measurements and psychological concepts (e.g., Beauchaine, 2001; de Vries, 2013; Quintana & Heathers, 2014). With regard to this increasing interest one should assume that there are general accepted and widely applied standards for HRV measurements. Unfortunately, it seems that this assumption oversimplifies the current scientific reality. Of course, the well-known standards provided by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) should serve as methodological and interpretative compendium. However, despite these Task Force guidelines (TFG), there are growing signs that HRV research is accompanied by methodological diversity, with respect to technological requirements and data processing algorithms, recording-specific characteristics, and/or reporting and presentation of common HRV parameters (e.g., see de Vries, 2013; Ellis et al., 2015; Koenig, Kemp, Beauchaine, Thayer, & Kaess, 2016; Nunan et al., 2010; Quintana & Heathers, 2014; Tak et al., 2009; Zahn et al., 2016). In particular, this status quo complicates meta-analytical efforts.

Moreover, to date, no generally accepted age- and gender-specific norm values for short-term HRV are available, although these are badly needed (above all, see de Vries, 2013; Nunan et al., 2010; Tak et al., 2009). One might hypothesize that the above-mentioned methodological heterogeneity in HRV research contributes to this unfortunate situation. Consequently, one aim of the present review is to quantify the methodological status quo for short-term HRV measurements in humans. Furthermore, we will outline the extent, to which previous studies adhere to the TFG of 1996. Finally, we will derive best practice criteria and recommendations based on these findings and recent literature.

Since the TFG (1996) represent a central starting point for the present review, we will now summarize the recommendations relevant for short-term measurements. Moreover, we subsequently outline updates/extensions that have been suggested since then in the relevant literature. The increasing importance and application of HRV as well as the complexity of assessments and analyses in this domain is also reflected in the interdisciplinary Task Force composition, consisting of mathematicians, engineers, physiologists, and clinical physicians (see also Schneider, 2015).

2.1.1. Task Force Recommendations for Short-Term Measurements

2.1.1.1. Recommendations for Time Domain Analyses

In the context of time domain methods, the TFG suggest a subdivision into statistical and geometric parameters. For short-term measurements, the investigation of the statistical parameters SDNN (standard deviation of interbeat intervals; IBIs), rMSSD (square root of the mean squared differences of consecutive IBIs), NN50 (number of successive IBIs differing by more than 50 ms), and pNN50 (percentage of NN50 IBIs) is recommended. At the same time, it is noted that rMSSD "has better statistical properties" (Task Force, 1996, p. 357) as compared to NN50 and pNN50, resulting in the recommendation to prefer rMSSD. Moreover, NN50 increases with the total number of analysed IBIs, complicating the comparison between studies (e.g., Appelhans & Luecken, 2006; Eller-Berndl, 2015; Kleiger et al., 2005; Task Force, 1996). Therefore, pNN50 should be preferred to NN50. The use of geometric methods (e.g., HRV triangular index) is recommended for longer time intervals only, starting with at least 20 minutes. In addition, the Task Force points out that it is inadmissible to compare parameters from different analysis intervals, because properties of statistical indices depend strongly on the length of the analysed interval.

2.1.1.2. Recommendations for Frequency Domain Analyses and Nonlinear Techniques

According to TFG (1996), the high frequency power (HF, 0.15 to 0.40 Hz) and the low frequency power (LF, 0.04 to 0.15 Hz) as well as the total power (TP, ≤ 0.40 Hz) and the LF/HF ratio need to be reported to adequately summarize results of spectral analysis. Additionally, HF and LF should be specified both, as absolute values (in ms^2) and normalized units (nu; HF nu = HF/(TP - VLF) × 100; LF nu = LF/(TP - VLF) × 100). Although the very low frequency power (VLF, 0.003 to 0.04 Hz) is mostly calculated by spectral analysis, this component should not be interpreted for short analysis intervals. The specific method that is used for calculating the power density spectrum should be named and described in detail in each relevant study. Most prominent methods being the non-parametric *Fast Fourier Transform* (FFT) and the parametric *Autoregressive Algorithm* (AR; e.g., see Allen et al., 2007; Appelhans & Luecken, 2006; Cygankiewicz & Zareba, 2013; de Vries, 2013; Kay & Marple, 1981; Task Force, 1996). Note that both methods are based on different assumptions and algorithms, leading to specific advantages and disadvantages (e.g., with respect to stationarity or periodicity of the signal; for details, see also Berntson et al., 1997; Friedman, Allen, Christie, & Santucci, 2002). Although results of FFT and AR are highly correlated (Hayano et al., 1991), there is still some dispute as to whether they are comparable (see Chemla et al., 2005; Ohara, Okita, Kouda, & Nakamura, 2016; Pichon, Roulaud, Antoine-Jonville, De Bisschop, & Denjean, 2006).

Finally, note that at the time of publication of the guidelines, nonlinear methods have not been investigated as nowadays. Hence, the TFG give no clear recommendations with respect to nonlinear methods, although the authors hint at the future potential of these methods. In brief, the numerous factors influencing HRV accompanied by multitudinous physiological interactions point to a highly complex system (e.g., see de Vries, 2013; Fatisson et al., 2016; Shaffer et al., 2014). Despite the constant reoccurrence of rhythms, it seems reasonable to assume that nonlinear trends are present in HRV as well. In recent years, researchers increasingly employed such nonlinear methods and tried to determine their advantages as compared to conventional methods (i.e., time and frequency domain analyses). In contrast to linear methods, assessing frequency distributions and rhythms, nonlinear methods seem to be better suited to take the complex structures underlying IBI time series into account (e.g., see Acharya et al., 2014; Cygankiewicz & Zareba, 2013; Goldberger, 1990; Hoshi, Pastre, Vanderlei, & Godoy, 2013; D. T. Kaplan et al., 1991; Kleiger et al., 2005; Quintana & Heathers, 2014; Sammito & Böckelmann, 2015; Task Force, 1996). Meanwhile, there are numerous methods and metrics utilizing theoretical approaches, such as chaos theory and nonlinear system theory (Goldberger, 1996; Huikuri, Mäkikallio, & Perkiömäki, 2003). Prominent methods are, inter alia, Poincaré plot analyses, detrended fluctuation analyses, power law HRV analyses, or entropy-based techniques (see in particular Acharya et al., 2014; Hoyer, 2009; Huikuri et al., 2003; Kleiger et al., 2005; Molina–Picó, Cuesta–Frau, Miró–Martínez, Oltra–Crespo, & Aboy, 2013; Voss, Baier, Schulz, & Bär, 2006).

2.1.1.3. Technical Equipment and Analysis Interval

The TFG (1996) recommend the use of an electrocardiogram (ECG) at a sampling rate of 250-500 Hz or higher. A suitable interpolation of the ECG signal can compensate lower sampling rates; thus, a sampling rate of 100 Hz represents the absolute minimum. Generally speaking, the ECG equipment should comply with the current technical standards. To determine reliable HRV parameters, a rule of thumb for the frequency domain is that the “recording should last for at least 10 times the wavelength of the lower frequency bound of the investigated component” (Task Force, 1996, p. 364). Therefore, it follows that at least a one-minute recording is required for HF and at least two minutes for LF. However, to achieve a uniform standardization, the Task Force recommends a time interval of five minutes for short-term measurements. Note that the TFG do not discriminate between recording and analysis intervals. Moreover, there is still no uniform definition of HRV short-term measurement (especially with regard to the limits of the analysis interval). As a result, some authors do not analyse any fixed time period, but a certain number of interbeat intervals instead (see, for example, Capa & Audiffren, 2009; de Guevara et al., 2004; Grimaldi et al., 2010; Ikawa et al., 2001; Kunz et al., 2012). This complicates the comparability of different studies.

2.1.1.4. Influences, Artefact Clean-Up, Interpretation of HRV Components

For short-term measurements of HRV, there is broad consensus that influences affecting the physiological processes of heart beat modulation should be held constant as far as possible. The TFG (1996) do not contain a definite list of such influences; however, the authors note that the HRV may be affected, for example, by exercise, drugs or medications, various diseases, circadian rhythm, respiration, and posture of subjects during assessment.

Since recording artefacts (e.g., brief interruptions of measurement due to involuntary movements of the subject or ectopic beats) may affect HRV parameters, a manual inspection and (if necessary) post-processing of the data is recommended. The interpretation of the HRV components is, at least partially, ambiguous. It seems to be undisputable that rMSSD, pNN50, and HF reflect vagal activity, while SDNN and TP are indices representing overall HRV. In contrast, the Task Force (1996) emphasizes that there is some uncertainty with respect to LF (possibly sympathetic regulation) and LF/HF (possibly sympathovagal balance).

2.1.2. Additional Recommendations and Influences on HRV

Since their publication in 1996, there has been no principal update of the TFG. However, several studies have been examining specific aspects of HRV in more detail. Especially the physiological interpretation of HRV parameters (above all LF, VLF, and LF/HF) and the use of nonlinear methods have received much attention and have been discussed and extended considerably (e.g., see Acharya et al., 2014; Berntson et al., 1997; Billman, 2013; Cygankiewicz & Zareba, 2013;

Eckberg, 1997; Goldberger, 1996; Heathers, 2014; Hoshi et al., 2013; Huikuri et al., 2003; Kleiger et al., 2005; Quintana & Heathers, 2014; Sammito & Böckelmann, 2015; Shaffer et al., 2014).

There is one aspect worth mentioning which already had been briefly mentioned within the TFG (Task Force, 1996), and this is about keeping undesired influences and environmental factors constant or about controlling such factors. In what follows, we provide a summary of those factors for which proximal influences on HRV are well documented. Note, however, that it is not possible to take all potential external and internal factors influencing HRV into account (a comprehensive overview is given by Fatisson et al., 2016). Therefore, the following list must be regarded as an attempt to summarize the most important caveats in this vein (see also de Vries, 2013).

2.1.2.1. Respiration

As already noted in the introduction, respiration exerts a strong influence on HRV, especially on those parameters reflecting parasympathetic activity. This is a highly interesting phenomenon in itself, usually referred to as respiratory sinus arrhythmia (i.e., respiration-synchronous fluctuations of heart rate; RSA; see, for example, Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; Eller-Berndl, 2015; Grossman & Taylor, 2007; Shaffer et al., 2014). The implications of RSA for HRV measurement have been discussed intensely, with four approaches seem to be frequently applied, each of them with certain pros and cons: the recording and statistical inspection of respiratory influences (e.g., by means of analyses of covariance, ANCOVA; Allen et al., 2007), the specification of respiratory cycles (also known as paced breathing; i.e., breathing within a given rhythm; Grossman, Karemaker, & Wieling, 1991; Grossman & Taylor, 2007), the use of different correction formulas (e.g., correcting for breathing rates and tidal volume; Ritz, 2009; Ritz, Thoens, & Dahme, 2001), and the preference for spontaneous breathing (for a more detailed discussion, see additionally Berntson et al., 1997; de

Vries, 2013; Denver, Reed, & Porges, 2007; Fonseca, Beda, Miranda de Sá, & Simpson, 2013; Hirsch & Bishop, 1981; Houtveen, Rietveld, & de Geus, 2002).

In general, low breathing rates tend to increase RSA, while fast breathing leads to a reduction of parasympathetic activity (Allen et al., 2007; Grossman et al., 1991; Grossman & Taylor, 2007; Telles, Singh, & Balkrishna, 2011). Additionally, vagal heart rate modulation depends on respiratory depth and carbon dioxide content as well (Houtveen et al., 2002). From a psychological perspective, it should also be considered that paced breathing is likely to produce unintentional emotional states (Philippot, Chapelle, & Blairy, 2002). However, special attention should be paid to breathing when respiration rates considerably differ between experimental conditions or groups (Allen et al., 2007; Grossman & Taylor, 2007).

To summarize, there are no definite guidelines when it comes to the influence of respiration on HRV parameters. In this respect, researchers are well advised to adhere to a general recommendation proposed by Allen and colleagues (2007): Minimize the likelihood of different breathing rates (varying between different conditions or groups) by a good and carefully planned experimental design.

2.1.2.2. Relationship between HRV and Heart Rate

Due to RSA, the association between heart rate and HRV must also be noted: However, the inverse relationship between HRV and heart rate (positive correlation between HRV and IBI, respectively) is not only attributable to physiological underpinnings, but also to mathematical reasons (Billman, 2013; Sacha, 2013, 2014; Sacha, Barabach, et al., 2013; Sacha & Pluta, 2005, 2008). That is, the variability of IBIs increases as heart rate decreases. As the mathematical bias is produced by the nonlinear association between heart rate and IBI, the authors recommend to divide the time domain HRV indices by the mean IBI (coefficient of variation, CV). The components of the power spectrum should therefore be divided by the squared average IBI.

Figure 3 illustrates this approach by plotting the average IBI against SDNN and the CV of IBIs. As can be seen, this simple transformation reduces the dependence of HRV parameters on mean IBI (or heart rate). Although the Task Force (1996) provides no clear recommendation in this regard, the CV of IBIs seems to be a useful index for short-term HRV and is treated as an indicator of overall HRV (e.g., Booij et al., 2006; Ikawa et al., 2001).

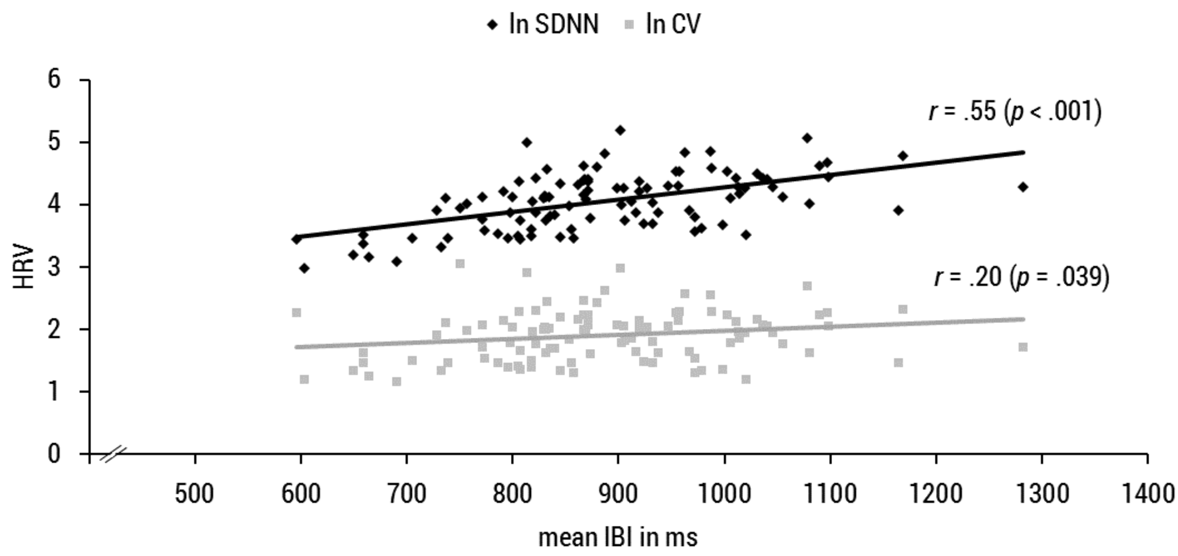


Figure 3. Relationship between mean interbeat interval (IBI) and HRV. The positive correlation between heart variability (HRV) parameters and mean IBI is considerably smaller, when dividing the standard deviation of IBIs (SDNN) by the average IBI (also known as coefficient of variation, CV). Data shown refer to the data set underlying Chapter III (N = 103); ln = natural logarithm.

2.1.2.3. Further Influences on HRV

There are additional factors influencing HRV, and some of these can be easily assessed by asking subjects: (a) *Age* of the participants is one such factor, and it has been consistently found that HRV decreases with age (e.g., Abhishekh et al., 2013; Agelink et al., 2001; Almeida-Santos et al., 2016; Antelmi et al., 2004; Eller-Berndl, 2015; Voss et al., 2015; Zhang, 2007). (b) *Gender* of the participants influences HRV as well, and hormonal differences appear to be of crucial importance here (Eller-Berndl, 2015; Voss et al., 2015). More specifically, younger women show higher heart rates as well as increased parasympathetic and decreased sympathetic activity as compared to age-matched males, and these differences seem to be decreased with age (see also Antelmi et al., 2004; Fagard, Pardaens, & Staessen, 1999; Koenig & Thayer, 2016; Young & Leicht, 2011). (c) Inconsistent findings have been reported with respect to *body mass index* (BMI) as a ratio of weight and height: Some studies find no difference between normal and obese participants (e.g., Antelmi et al., 2004), while other studies report decreased HRV values for overweight or obese individuals (e.g., Almeida-Santos et al., 2016; Birch, Duncan, & Franklin, 2012; de Vries, 2013; Felber Dietrich et al., 2008; Karason, Mølgaard, Wikstrand, & Sjöström, 1999). (d) *Nutrition* and *physical activity* also play a key role in HRV. A diet rich in omega-3 fatty acids and fish is positively associated with HRV (e.g., Hansen, Dahl, Bakke, Frøyland, & Thayer, 2010; Singh et al., 2000). Overall, regular exercise seems to have positive influences on HRV (e.g., De Meersman, 1993; Felber Dietrich et al., 2008; Pichot et al., 2005; Reland, Ville, Wong, Senhadji, & Carré, 2004; Rennie et al., 2003). As a methodological note, immediate physical activity (accompanied by higher heart rates) and heavy meals should be avoided in the context of HRV measurement, due to strong proximal physiological influences (e.g., Grossman & Taylor, 2007; Lu, Zou, Orr, & Chen, 1999; Quintana & Heathers, 2014; Tak et al., 2009; Tortora & Derrickson, 2006; Valentini & Parati, 2009). (e) Certain kinds of *medication* (e.g., beta-blockers, antidepressants) as well as the consumption of psychoactive substances, such as *alcohol*, *nicotine,* or *caffeine* exert a strong influence on HRV (e.g., Acharya, Joseph, Kannathal, Lim, & Suri, 2006; Aronson & Burger, 2001; de Vries, 2013; Dinas, Koutedakis, & Flouris, 2013; Eller-Berndl, 2015; Flanagan et al., 2002; Hayano et al., 1990; Licht et al., 2008; O'Regan, Kenny, Cronin, Finucane, & Kearney, 2015; Rauh, Burkert, Siepmann, & Mueck-Weymann, 2006; Richardson et al., 2004). (f) *Physical* and *mental diseases* (e.g., cardiovascular diseases, diabetes mellitus, anxiety disorders, depression) are well confirmed to be associated with HRV anomalies (for overviews, see Appelhans & Luecken, 2006; Beauchaine & Thayer, 2015; ChuDuc et al., 2013; Cygankiewicz & Zareba, 2013; Eller-Berndl, 2015; Hoyer, 2009; La Rovere et al., 2003; Riganello et al., 2012; Stein & Kleiger, 1999; Task Force, 1996; Thayer & Lane, 2000, 2007).

In addition, great care must be taken when measuring HRV, as subjects' posture (Acharya et al., 2005; Cipryan & Litschmannova, 2013; Dietrich et al., 2010; Kowalewski & Urban, 2004; Mahananto, Igasaki, & Murayama, 2015; Radhakrishna et al., 2000; Vuksanovic, Gal, Kalanj, & Simeunovic, 2005), activity during measurement (e.g., Grossman & Taylor, 2007; Houghton & Gray, 2001; Quintana & Heathers, 2014), and time of day (by circadian patterns; e.g., Bilan et al., 2005; Boudreau, Yeh, Dumont, & Boivin, 2012; Eller-Berndl, 2015; Guo & Stein, 2002; Huikuri et al., 1990; Pumprla et al., 2002) are also important influences. To conclude, there are numerous factors influencing HRV; excellent overviews are given by Valentini and Parati (2009) as well as by Fatisson and others (2016). Also, note that these factors deserve even more attention especially when a random subject assignment to experimental conditions/groups is not possible (e.g., in a quasi-experimental investigation).

2.1.3. Obstacles and Challenges in HRV Research

As mentioned, there is a steadily increasing number of studies, findings, and recommendations in HRV research. Yet, generally accepted reference and norm values for short-term measurements of HRV are still scarce (de Vries, 2013; Nunan et al., 2010). Two decades ago, the TFG (Task Force, 1996) urged researchers to provide age and gender specific norms for at least basic HRV characteristics. Although such norm values are crucial for scientific progress and clinical evaluations, the situation is still far from satisfactory (Nunan et al., 2010).

Given the sheer number of studies that have been published during the past two decades, one might be tempted to assume that the available database is sufficient for the identification of standard values. However, in their attempt to extract such norm tables, Nunan and colleagues (2010) noted that only 44 out of 3,141 studies were suitable for this project. By and large, there are four main reasons contributing to this state of affairs: (a) A majority of studies examined long-term HRV. (b) Sample sizes were often too small (i.e., $N < 30$). (c) Studies often investigated clinical samples in the absence of a healthy control group. (d) The TFG (Task Force, 1996) were often not fully adhered to, which has led many researchers to reporting inappropriate and not reporting recommended parameters. Moreover, the norm values that have eventually been sampled by Nunan and colleagues (2010) have been noticeably discrepant to former norm values as provided by the TFG (Task Force, 1996). The authors attributed these differences to the heterogeneous methodological implementation of HRV short-term measurements, and to the non-reporting of important details.

There have been additional promising attempts to generate norm values for short-term measurements of HRV, suggesting a strong need for specific values for age-groups, gender, and other variables (e.g., Agelink et al., 2001; de Vries, 2013; Michels, Clays, et al., 2013; Task Force, 1996). However, thus far these attempts for systematization have not been successful due to many (often un-anticipated) impediments. For example, deviating cut-off values for LF and HF have been used (see, for example, Fukusaki, Kawakubo, & Yamamoto, 2000), or even a reference to the TFG is entirely missing (see, for example, Zhang, 2007). As a consequence, the establishment of norm value tables is still a highly important task, and the resulting norms need to take numerous characteristics and influences into account, including various characteristics of participants, the methodical setting, and the nature of the statistical analysis (Nunan et al., 2010; Sammito & Böckelmann, 2015).

In sum, the recent boom in HRV research is (still) accompanied by several methodological difficulties and disagreements (e.g., see de Vries, 2013; Ellis et al., 2015; Koenig et al., 2016; Nunan et al., 2010; Quintana & Heathers, 2014; Tak et al., 2009; Zahn et al., 2016). According to our literature research, there is currently no publication that systematically records this methodological diversity in the context of short-term measurements and independent of the research questions of the studies. Moreover, a systematic comparison between research status quo and TFG (Task Force, 1996) is still missing. The present review aims at closing this gap.

2.2. Methods and Materials

In order to standardize our procedure and largely adhere to current quality standards, we closely followed the PRISMA statement provided for systematic reviews (see Liberati et al., 2009; Ziegler, Antes, & König, 2011).

2.2.1. Review Questions

Our goal is to summarize and analyse the methodological characteristics of studies including measurements of HRV. Note that the specific research questions of the respective studies are not of interest to us and therefore not considered. For practical reasons, we will employ three inclusion criteria: (a) Studies assessing the HRV in humans, (b) as a short-term measurement, (c) within a psychological context (i.e., listed in a psychological database). The present review is conducted to answer the following questions: (1) What is the methodological status quo when assessing HRV in humans? (2) Are there measurement standards with respect to procedure, analysis, and interpretation? (3) To what extent do previous studies consider the TFG of 1996? (4) Which best practice criteria can be derived from these findings?

2.2.2. Search Strategy

We conducted an extensive literature review using the database PsycINFO to identify studies investigating short-term HRV published between January 2000 and the time of search (October 29th, 2013). Therefore, we only used the search term *heart rate variability* (title, abstract, keywords). There was no other limitation. A total of 1,665 articles were identified. In an initial step, we extracted the authors, titles, publication years, sources, and abstracts of these articles.

2.2.3. Inclusion and Exclusion Criteria for Paper Selection

The process for selecting the studies considered in this review is summarized in Figure 4. First, we checked the full-text-access of these articles by browsing the PsycINFO database. If full texts were not available, we additionally searched in the corresponding journals, the world-wide web, or other databases. Applying this strategy, we were able to locate 1,202 full-texts, corresponding to a quote of 72.2 %.

Second, we examined the titles and abstracts of the articles for eligibility with regard to different keywords. To integrate only comparable studies, we excluded long-term measures (search terms: *24-hour, long-term, sleep, 24 h, polysomnography*), animal-studies (search terms: *animal, rat, goat, dog, horse, cow, pig, lamb, swine, sheep, primate, quail*), reviews and meta-analyses (search terms: *review, meta-analysis*), as well as chapters and dissertations (search terms: *book, chapter, dissertation*). Furthermore, articles not written in English or German were excluded. Just as comments, replies, or studies with a mean sample age less than 18 years.

Upon application of these criteria, n = 736 studies remained in our data base. For practical and economic reasons, we drew a sample of 450 articles from this corpus, reviewed by three raters. Considering the present population of n = 736, this sample size could be assessed as very representative (Borg, 2003; Kauermann & Küchenhoff, 2011). In the case that a so-selected study contained one of the previous exclusion criteria, it was noted accordingly and a new study was drawn at random. Seven additional papers were used to develop the classification system, which we will explain below. Therefore, our final sample included N = 457 articles corresponding to 27.4% of the original number (see Appendix).

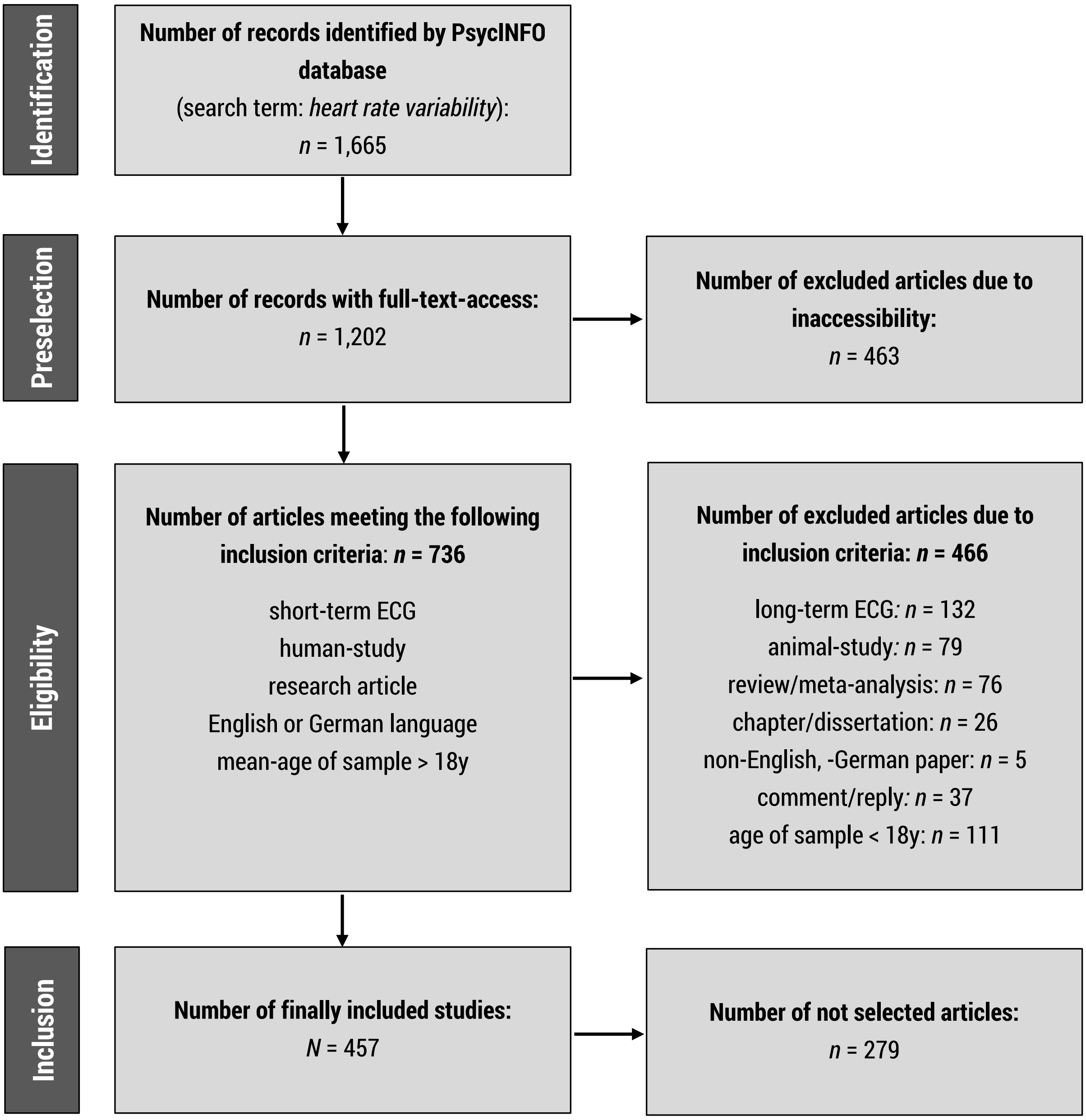


Figure 4. Flow chart illustrating search strategy and selection process. ECG = electrocardiogram.

2.2.4. Classification System and Data Extraction

First of all, we developed a system aiming to categorize and assess the obtained studies, to enable us to evaluate each individual study according to specific criteria. To identify appropriate variables and criteria, we used the following three sources: First, we consulted the TFG (Task Force, 1996) for recommendations on short-term measurements of HRV. Second, we took into account additional criteria as proposed in recent articles (e.g., by Berntson et al., 1997; Brennan, Palaniswami, & Kamen, 2001; Molina–Picó et al., 2013; Sacha, 2013). Finally, we randomly selected seven studies from our sample, to verify the feasibility of the previously investigated specifications. Three independent raters categorized these seven studies according to a first prototype of our classification system followed by mutual validation. Some variable characteristics needed revisions or extensions; for example, type of frequency band transformation. In addition, we also created entirely new variables, as for example, analysis interval based on the number of IBIs. Our resulting classification system consisted of three central components: (a) Variables providing general descriptions of the study (twelve variables), (b) variables informing about the setting of the physiological data collection (17 variables), and (c) characteristics of data presentation and interpretation (18 variables).

The general description of the study includes *title*, *authors*, *journal*, *publication year*, *impact of the corresponding journal* [2], *research field*, *(sub-) sample sizes*, *mean age of subjects,* and *reference to TFG*. Data collection is characterized by the following variables: *daytime of measurement*, *control of breathing*, *length of recording interval*, *length of analysis interval*, *analysis interval based on the number of IBIs*, *used measuring device*, *sampling rate of the instrument*, *used software*, *type of frequency band transformation*, *control of various substance influences* (nicotine, caffeine, alcohol, medication), c*ontrol of immediate activity*, *activity of subjects during measurement*, *posture during measurement,* and *artefact clean-up*. Finally, the category data presentation and interpretation includes the following variables: *heart rate*, *average IBI*, *statistical parameters of the time domain analysis* (SDNN, rMSSD, pNN50, CV), *parameters of the frequency band analysis* (TP, HF, HF nu, LF, LF nu, VLF, LF/HF), *nonlinear or geometric analyses*, *result interpretation,* and *number of reported*

[2] Retrieved from http://www.scimagojr.com/ (Scimago Lab, 2017).

HRV parameters (time domain, frequency domain, total). In case of the variables HF and LF we did not distinguish if HF and LF were specified in terms of absolute, logarithmic, or relative values.

Tables 2 to 4 provide all variables and their characteristics as well as a brief explanation as to why we included this variable. In a next step, we categorized all articles according to this classification system. Uncertainties and questions during this process were collectively discussed until a consensus was emerged. When information about study descriptions or data collection were not available, these were coded as *not mentioned*. We further coded whether or not the corresponding HRV parameters were reported in the respective article (reported versus not reported). Reported means in this case that the corresponding parameter has been specified in the results or discussion section of the respective study, regardless of whether or not the calculation of the parameter has been described in the methods. When an article included several studies, we only integrated the first study in our review. Therefore, we use the terms article, paper, and study synonymously. One drawback of the applied approach is that the publication bias or the selective presentation of results influence our data. We will address this issue later. Finally, note that it is impossible to present the whole classification system including all reviewed studies within this chapter. Therefore, the classification system is available upon request.

Table 2

Classification System: Descriptive Variables

Variable	Description	Characteristics	Reason for selection
Title	The title of the article.	--	Purely informative reasons.
Author	The author(s) of the article.	--	Purely informative reasons.
Journal	The journal publishing the article.	--	Identification of impact factors.
Impact factor: cpd 2y (Garfield, 1972; Jones, Huggett, & Kamalski, 2011)	Journal impact as a measure of average citations out of all citable articles of a journal within the previous two years.	--	Examining the relationship between number of reported HRV parameters and scientific success.
Impact factor: SJR (González-Pereira, Guerrero-Bote, & Moya-Anegón, 2010; Jones et al., 2011)	Journal impact additionally weighting counted citations.	--	Examining the relationship between number of reported HRV parameters and scientific success.
Publication year	Publication year of the study.	--	Identification of impact factors and investigation of temporal trends.
Reference to TFG (Task Force, 1996)	Did the authors refer to the TFG of 1996?	1: no 2: yes	Investigation of TFG influence and presence.
Mean sample age	The subjects' average age.	--	Influence of age on HRV (Voss et al., 2015).
Research field	Allocating the study to a research field.	1: neuroscience 2: mental disorders 3: cognitive psychology 4: positive psychology 5: stress research 6: music, arts, sports 7: physical illness 8: bio-/ neurofeedback 9: emotion research 10: basic research 11: pain research	Investigation of the distribution across different research fields.
Total sample size	Total number of subjects.	--	For informational purposes.
Percentage of women	Percentage of women within the sample.	--	Effect of gender on HRV (Voss et al., 2015).
Percentage of men	Percentage of men within the sample.	--	Effect of gender on HRV (Voss et al., 2015).

Notes. cpd 2y = citations per document in the previous two years; HRV = heart rate variability; SJR = SCImago Journal Rank; TFG = Task Force guidelines.

Table 3

Classification System: Characteristics of HRV Data Collection

Variable	Description	Characteristics	Reason for selection
Time of day	Daytime of HRV measurements.	1: in the morning 2: in the afternoon 3: all the day 4: in the evening 5: at night	Circadian influences on HRV (e.g., Boudreau et al., 2012; Eller-Berndl, 2015; Guo & Stein, 2002; Huikuri et al., 1990).
Handling of respiration	Applied approach to deal with subjects' respiration.	1: no assessment 2: not specified exactly 3: recording 4: paced breathing	Well-known influence of respiration on HRV (Allen et al., 2007; Denver et al., 2007; Grossman & Taylor, 2007; Ritz, 2009).
Recording interval	Length of (baseline) recording interval in minutes.	--	To increase the likelihood of an artefact-free interval, the recording interval should be larger than the analysis interval (de Vries, 2013).
Analysis interval	Length of (baseline) analysis interval in minutes.	1: not applicable[a]	TFG recommendation to use a five-minute interval (Task Force, 1996).
Analysis interval based on IBIs	Number of selected IBIs for analysis.	1: not applicable[a]	Some researchers analyse a certain number of IBIs instead of a fixed time interval (Capa & Audiffren, 2009; de Guevara et al., 2004; Grimaldi et al., 2010).
Measuring device	Hardware used for recording heart rate/IBIs.	1: ECG 2: PPG	ECG is recommended by the TFG; PPG seems to be more inaccurate (Schäfer & Vagedes, 2013; Shaffer et al. , 2014; Task Force, 1996).
Sampling rate (in Hz)	Sampling rate of the measurement device.	--	The TFG recommend a sampling rate of 250 Hz or more (Task Force, 1996).
Software	Used software for calculation of HRV parameters.	--	Exclusively for informational purposes.
Spectral analysis	Method of power spectral density analysis.	1: FFT 2: AR 3: FFT & AR 4: miscellaneous 5: no transform/ not mentioned	Various methods for spectral analysis are available, leading to similar, but not identical values (Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; Chemla et al., 2005).
Substance influences	Assessment of substance influences (nicotine, caffeine, alcohol, medication).	1: yes 2: no/ not mentioned	Each of these substances may affect heart rate and thus HRV (Aronson & Burger, 2001; Dinas et al., 2013; Flanagan et al., 2002; O'Regan et al., 2015; Rauh et al., 2006; Richardson et al., 2004).

Table 3 (continued)

Classification System: Characteristics of HRV Data Collection

Variable	Description	Characteristics	Reason for selection
Immediate activity	Assessment of physical activity and food intake.	1: yes 2: no/ not mentioned	Immediate physical activity affects the HRV, just as heavy meals (e.g., Lu et al., 1999; Quintana & Heathers, 2014; Tak et al., 2009; Valentini & Parati, 2009).
Activity during measurement	Activity of subjects during HRV recording.	1: relaxation 2: visual task 3: auditory task 4: cognitive task 5: motoric task 6: combination of 3-6	Almost every activity or movement affects measurement of HRV (e.g., Grossman & Taylor, 2007; Houghton & Gray, 2001; Quintana & Heathers, 2014; Tortora & Derrickson, 2006).
Posture during measurement	Posture of the subjects during recording.	1: supine 2: sitting 3: standing 4: moving	Heart rate and HRV are influenced by subjects' posture (Acharya et al., 2005; Cipryan & Litschmannova, 2013; Mahananto et al., 2015; Radhakrishna et al., 2000; Vuksanovic et al., 2005).
Artefact clean-up	Post processing of data in terms of artefact correction.	1: yes 2: no/ not mentioned	Artefacts should always be identified and removed (Task Force, 1996).

Notes. If corresponding information was not available, we declared this as not mentioned. AR = Autoregressive Algorithm; ECG = electrocardiogram; FFT = Fast Fourier Transform; HRV = heart rate variability; IBI = interbeat interval; PPG = photoplethysmograph; TFG = Task Force guidelines.

[a] When authors analysed a fixed number of IBIs, we declared the length of the analysis interval as not applicable and vice versa.

Table 4

Classification System: Presentation and Interpretation of Results

Variable	Description	Characteristics	Reason for selection
Heart rate, mean IBI	Reporting of heart rate and average IBI.	1: no 2: yes	Basis for the calculation of HRV parameters (Appelhans & Luecken, 2006; Berntson et al., 1997; Shaffer et al., 2014).
SDNN, rMSSD, pNN50, CV	Reporting of statistical time domain parameters SDNN, rMSSD, pNN50, and CV.	1: no 2: yes	SDNN, rMSSD, pNN50: TFG recommend to report these parameters (Task Force, 1996). CV: Represents total HRV and is less dependent on heart rate (e.g., Ikawa et al., 2001; Sacha, 2013).
LF, LF nu, HF, HF nu, LF/HF, TP	Reporting of frequency domain parameters LF, LF nu, HF, HF nu, LF/HF, and TP.	1: no 2: yes	TFG recommend to report these parameters (Task Force, 1996).
VLF	Reporting of the frequency domain parameter VLF.	1: no 2: yes	VLF should not be interpreted within short-term HRV (Task Force, 1996).
Nonlinear or geometric analyses	Reporting of nonlinear or geometric analysis methods and their results.	1: no 2: yes	In the aftermath of the TFG the importance of nonlinear and geometric methods increased (e.g., Acharya et al., 2014; Hoshi et al., 2013; Kleiger et al., 2005; Quintana & Heathers, 2014).
Result interpretation	Interpretation of HRV values using an external criterion or a comparison within the sample.	--	Despite several attempts to provide standard values, they do not exist so far to a sufficient extent (e.g., Agelink et al., 2001; Michels, Sioen, et al., 2013; Nunan et al., 2010).
Number of reported HRV parameters	Number of reported parameters recommended by the TFG (time domain: SDNN, rMSSD, pNN50; frequency domain: HF, LF, LF/HF, TP).	--	To provide a simple quality rating.

Notes. If a corresponding information was not available, we declared this as not mentioned. CV = coefficient of variation of IBIs; HF = high frequency power; HF nu = normalized units of HF; HRV = heart rate variability; IBI = interbeat interval; LF = low frequency power; LF nu = normalized units of LF; LF/HF = ratio of LF and HF; pNN50 = percentage of successive IBIs with a difference > 50 ms; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TFG = Task Force guidelines; TP = total power; VLF = very low frequency power.

2.2.5. Data Analysis

All data were transferred into IBM Statistics SPSS 23. Missing or illogical values were sought, supplemented, and/or corrected by re-examining the article in question. In a first step and to explore the general state of affairs, we will report descriptive analyses. Next, we will compare the obtained data with the TFG (Task Force, 1996). In addition, we report inferential statistics analysing systematic differences between studies, depending on their reference to the TFG. Finally, we will analyse relationships between several variables, such as between the impact factors of the journals and the number of reported HRV parameters. This is linked to the question whether we can find better standards in the best journals (i.e., the most quoted journals). As most of the variables are not normally distributed respectively metric, we compute tests for categorical data and nonparametric tests (Phi coefficients [ϕ], Mann-Whitney *U*-tests, Spearman correlations [r_s]; two-tailed, $p < .05$). According to this logic, we will report medians plus means and standard deviations in most cases. Note that parametric counterparts reveal similar results.

2.3. Results

2.3.1. Characteristics of the Included Studies

2.3.1.1. Sample Characteristics

The 457 studies included in the present review represent an enormous variability with respect to their descriptive characteristics (for an overview, see Table 5). Average sample size per study is *M* = 91.83, the median being *Mdn* = 40. The standard deviation (*SD* = 409.84) indicates a large heterogeneity with respect to sample sizes, varying between N_{min} = 1 and N_{max} = 6,652 participants per study. Across all studies, the ratio of men to women is almost equal, with the median percentage of women being slightly higher (*Mdn* = 53.85). Mean sample age is *M* = 34.83 (*SD* = 14.23), with the youngest sample being M_{min} = 18.43 and the oldest M_{max} = 77.80 years.

Table 5

Sample Size, Gender Distribution, Mean Sample Age, Publication Year, and Impact Factors of the Included Studies/ Journals (N = 457)

Variable	*N*	*M (SD)*	*Mdn*	*Mode*	*Min*	*Max*
Total sample size	457	91.83 (409.84)	40	20	1	6,652
Percentage of women (%)	434	54.36 (29.37)	53.85	100	0	100
Percentage of men (%)	434	45.65 (29.37)	46.15	0	0	100
Mean age of the sample	417	34.83 (14.23)	31.30	21.00	18.43	77.80
Publication year	457	2008 (3.41)	2009	2011	2000	2013
Journal impact: cpd 2y	450	2.90 (1.65)	2.78	2.93	0.00	15.23
Journal impact: SJR	450	1.21 (0.74)	1.11	1.10	0.00	5.71

Notes. Data for 2013 are not representative, as this year was not completely included in the present review. Smaller samples are attributable to unavailable data. cpd 2y = cites per document in the previous two years; SJR = SCImago Journal Rank.

2.3.1.2. Publication Year and Impact Factor

When analysing the distribution of publication years, it becomes apparent that the number of publications per year shows an increase (see Figure 5). We already mentioned this trend in the introduction. Note, however, that data for 2013 are not representative because we have not included the entire year in our research. In addition, we identified the impact factors relevant for the publication year of almost each article. It turns out that these journal impact factors vary considerably; that is, according to the SCImago Journal Rank (SJR) between *min* = 0.00 and *max* = 5.71 (*Mdn* = 1.11), and between *min* = 0.00 and *max* = 15.23 (*Mdn* = 2.78) when considering cites per document within the previous two years (cpd 2y; see Table 5). Both impact factors are highly correlated with $r_s = .901$ ($p < .001$).

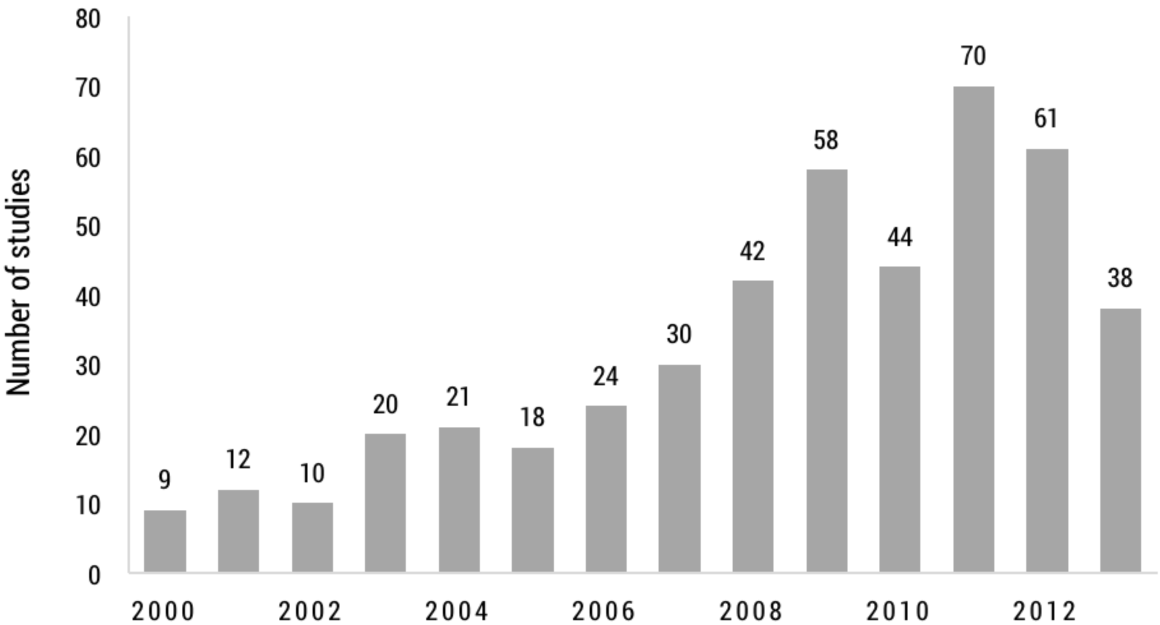


Figure 5. Publication years of reviewed studies (*N* = 457). The global increase of publications in recent years is also evident within the present sample. Data for 2013 are not representative, as only database entries until October 29th were considered.

2.3.1.3. Research Fields

Note that when categorizing studies according to specific research fields, there are many studies that are pertinent to multiple topics. In this case, we tried to make the most appropriate assignment. In addition, the number of studies that had to be subsumed under the label *miscellaneous* is quite large (i.e., *n* = 61, 13.3 %). One reason for this is that HRV measurements are applied in almost all kinds of research (such as spirituality, hypnosis, or PC games). Having this said, it is evident that a large body of research involving HRV measures has addressed research questions in the field of mental disorders (*n* = 140, 30.6 %). Research on physical illness (*n* = 62, 13.6 %) and stress research (*n* = 60, 13.1 %) also figures quite prominently. Figure 6 provides a comprehensive overview of all research fields.

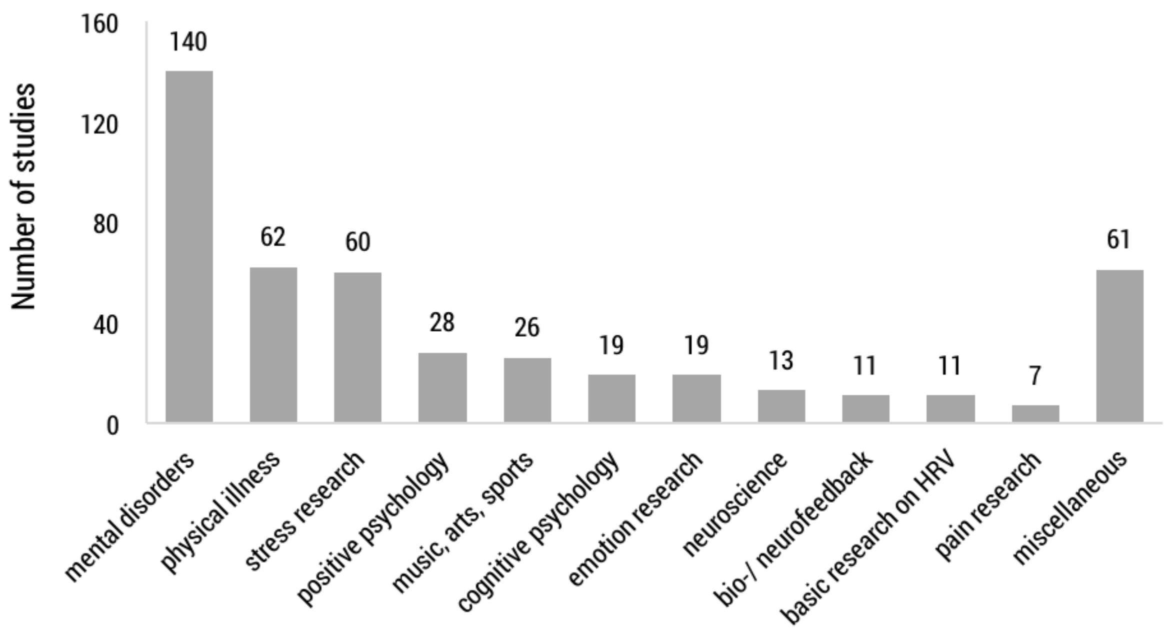


Figure 6. Frequency distribution of research fields of included studies (*N* = 457). HRV = heart rate variability.

2.3.1.4. Reference to Task Force Guidelines

Approximately two thirds of all studies (*n* = 298, 65.2 %) make explicit reference to the TFG (1996) and specify these – at least partially – as a methodological basis of their study. Conversely, about one third (*n* = 159, 34.8%) of studies do not consist of any observable reference to these guidelines, although all the studies were published after 1996 (i.e., after the publication of the TFG).

2.3.2. Basic Characteristics of HRV Data Collection

To understand the status quo of HRV short-term measurements, we will subsequently evaluate all relevant variables in a step by step fashion (see below). An important note in this context is that definite conclusions about a study are only possible if appropriate information is available from the article. Hence, a variable or characteristic that is coded as not mentioned can not be interpreted as ignored. In what follows, all descriptive statistics we report (predominantly: percentages) refer to the entire sample of studies (*N* = 457) unless we state explicitly otherwise. If several measuring sections are available within one paper, we will consistently refer to the description of the baseline measurement (which is typically the most exhaustive description of the methodology employed). Most importantly, we provide comparisons between the characteristics of the studies under consideration of the TFG (1996); these are summarized in Table 6.

2.3.2.1. Treatment of Respiration Effects

The respiration of the subjects was not controlled in 7.2 % of studies (*n* = 33). 37 studies (8.1 %) controlled breathing, which was not explained in detail. 84 studies (18.4 %) used a breathing belt or a similar device. Paced breathing is described in 7.4 % (*n* = 34) of the articles. The percentage of studies that do not specify this variable is large (*n* = 269, 58.9 %).

2.3.2.2. Daytime of Measurement

The daytime of the measurement, and thus the circadian influence is reported by about 37.6 % (*n* = 172) of the articles. 67 studies (14.7 %) took place in the morning, 59 (12.9 %) in the afternoon and 36 (7.9 %) during all daytime (except at night). Only 2.2 % (*n* = 10) of all studies were conducted in the evening or even at night.

2.3.2.3. Recording and Analysis Interval

The recording interval has been specified by a total of 405 studies (88.6 %). The average recording interval is *M* = 14.70 minutes (*SD* = 51.90), the median is *Mdn* = 5 minutes. In most articles, and consistent to the TFG, an interval of five minutes has been chosen (*n* = 149, 32.6 %). However, there are large variations (*min* = 0.5, *max* = 960), which are often related to the purpose and/or design of the studies. The analysis interval is not reported in 11.8 % of the articles (*n* = 54). Moreover, 8.3 % of the studies (*n* = 38) report a certain number of IBIs instead of a time interval. The most common analysis interval is again five minutes (*n* = 173, 37.9 % of studies), which corresponds to the requirements of the TFG. Accordingly, 62.1 % of the articles (*n* = 284) do not comply with this requirement or do not specify the relevant information. In 125 studies (27.4 %) both the recording interval and the analysis interval is five minutes. We will address this fact again in the discussion. When a fixed number of IBIs was defined for analysis (*n* = 38, 8.3 %), 256 consecutive intervals were preferred (*n* = 13, 2.8 %). However, in some cases significantly more intervals were selected, which is reflected in the mean and standard deviation (*M* = 455.68, *SD* = 508.89, *Mdn* = 256).

2.3.2.4. Measuring Instrument, Sampling Rate, and Spectral Analysis

The majority of studies follows the requirement to use an ECG (including belts and shirts) for the precise detection of R peaks (*n* = 420, 91.9 %). Only 5.7 % (*n* = 26) make use of a photoplethysmograph (PPG), while 2.4 % (*n* = 11) do not specify the measuring instrument. The results with respect to the sampling rate illustrate the technological progress since 1996: Median sampling rate is *Mdn* = 1000/1024 Hz, clearly surpassing the Task Force recommendations of 250-500 Hz. The equipment did not fulfil this requirement in 9.6 % of studies (*n* = 28). However, it becomes clear that the sampling rates of PPGs (*Mdn* = 100) are significantly lower than the ECG sampling rates (Mdn = 1000/1024), with $U = 285.00$, $z = -4.73$, $p < .001$, $r = -.28$. Devices with a sampling rate of 1000/1024 Hz were used most frequently (*n* = 178, 39.0 %). In 35.9 % of the papers (*n* = 164), no information about sampling rate is provided. The spectral analyses are most frequently based on the Fast Fourier Transform (*n* = 187, 40.9 %), while the Autoregressive Algorithm (*n* = 52, 11.4 %) and a combination of both methods (*n* = 13, 2.8 %) are used less often. Other methods (such as the Wavelet method) are reported only rarely (*n* = 10, 2.2 %). 195 articles (42.6 %) give no information in this regard. On the one hand, maybe no spectral analysis was calculated, secondly, because it is simply not reported. If we consider only studies reporting at least one parameter of spectral analysis (*n* = 357; 78.1 %), the following distribution is observable: Fast Fourier Transform with *n* = 179 (50.1 %), Autoregressive Algorithm with *n* = 50 (14.0 %), combination of both methods with *n* = 12 (3.4 %), other methods (*n* = 10, 2.8 %), and not specified with *n* = 105 (29.4 %).

2.3.2.5. Substance Influences

The control of substance influences varies with the particular substance under consideration. 60.8 % (*n* = 278) of all studies indicate that the individual medication was either queried or controlled for. The corresponding percentage for caffeine is only 39.4 % (*n* = 180). Nicotine and alcohol consumption have been queried for in 46.0 % (*n* = 210) respectively 42.0 % (*n* = 192) of all articles.

2.3.2.6. Activity prior and during Measurement, Posture, and Artefact Clean-Up

The control for activities immediately before measurement, such as exercise or food consumption, is reported by 43.5 % (*n* = 199) of all studies. 72.4 % of the measurements (*n* = 331) took place under resting conditions. In a few studies, subjects were presented additional stimuli during HRV recording (a total of *n* = 61, 13.4 %). In this context, it should be noted that a majority of the authors decided to record the HRV with their subjects being seated (*n* = 194, 42.5 %). Lying subjects were recorded in 116 studies (25.4 %). Other postures or positions were adopted only rarely (*n* = 7, 1.6 %). 140 articles (30.6 %) report no information about the posture of their subjects. The clean-up of artefacts, as a basis for further data analyses, is reported in about half of all studies (*n* = 216, 47.2 %), regardless of what kind of clean-up had been used.

Table 6

Review Results Compared to the TFG (Task Force, 1996): HRV Data Collection (N = 457)

Variable	Characteristics	Frequency (%)	*Descriptive statistics*	TFG remark
Time of day	in the morning	67 (14.7)	--	Circadian influences on HRV require the indication of daytime.
	in the afternoon	59 (12.9)		
	all the day	36 (7.9)		
	in the evening	7 (1.5)		
	at night	3 (0.7)		
	not mentioned	285 (62.4)		
Handling of breathing	no assessment	33 (7.2)	--	Respiration shows strong influences on HRV. No recommendation whether breathing should be paced, recorded, or spontaneous.
	not specified exactly	37 (8.1)		
	recording	84 (18.4)		
	paced breathing	34 (7.4)		
	not mentioned	269 (58.9)		
Recording interval (min)[a]	five minutes	149 (32.6)	M = 14.70 (SD = 51.90)	Recommendation to use five minutes. There is no distinction between recording and analysis interval.
	ten minutes	68 (14.9)	Mdn = 5	
	15 minutes	24 (5.3)	$Mode$ = 5	
	miscellaneous	164 (35.9)	Min = 0.5	
	not mentioned	52 (11.4)	Max = 960	
Analysis interval (min)[a]	five minutes	173 (37.9)	M = 7.41 (SD = 8.84)	
	ten minutes	39 (8.5)	Mdn = 5	
	three minutes	33 (7.2)	$Mode$ = 5	
	miscellaneous	120 (26.3)	Min = 0.5	
	not applicable[b]	38 (8.3)	Max = 60	
	not mentioned	54 (11.8)		
Analysis interval based on IBIs[a]	256 IBIs	13 (2.8)	M = 455.68 (SD = 508.89)	No TFG recommendation.
	100 IBIs	6 (1.3)	Mdn = 256	
	300/ 550 IBIs	4 (0.9)	$Mode$ = 256	
	miscellaneous	11 (2.4)	Min = 100	
	not applicable[b]	365 (79.9)	Max = 2000	
	not mentioned	54 (11.8)		
Measuring device	ECG	420 (91.9)	--	ECG should be preferred, while conforming to current technical standards.
	PPG	26 (5.7)		
	not mentioned	11 (2.4)		
Sampling rate[a]	1000/1024 Hz	178 (39.0)	M = 830.09 (SD = 565.49)	At least 250-500 Hz, ideally even more.
	500/512 Hz	54 (11.8)	Mdn = 1000/1024	
	200 Hz	17 (3.7)	$Mode$ = 1000/1024	
	miscellaneous	44 (9.6)	Min = 40	
	not mentioned	164 (35.9)	Max = 8000	

Table 6 (continued)

Review Results Compared to the TFG (Task Force, 1996): HRV Data Collection (N = 457)

Variable	Characteristics	Frequency (%)	*Descriptive statistics*	TFG remark
Spectral analysis	FFT AR FFT & AR miscellaneous no transformation/ not mentioned	187 (40.9) 52 (11.4) 13 (2.8) 10 (2.2) 195 (42.6)	--	Distinction between parametric and nonparametric methods, each with pros and cons. Therefore, precise details on the chosen method are necessary.
Substance influences: nicotine	yes no/ not mentioned	210 (46.0) 247 (54.0)	--	No TFG recommendation.
Substance influences: caffeine	yes no/ not mentioned	180 (39.4) 277 (60.6)	--	No TFG recommendation.
Substance influences: alcohol	yes no/ not mentioned	192 (42.0) 265 (58.0)	--	No TFG recommendation.
Substance influences: medication	yes no/ not mentioned	278 (60.8) 179 (39.2)	--	Many medications with direct or indirect influences.
Immediate activity	yes no/ not mentioned	199 (43.5) 258 (56.5)	--	Known influences on HRV.
Activity of subjects during measurement	relaxation visual task auditory task cognitive task motoric task combination not mentioned	331 (72.4) 24 (5.3) 7 (1.5) 16 (3.5) 8 (1.8) 6 (1.3) 65 (14.2)	--	Recommendation to ensure constant study conditions and to describe them in detail.
Posture during measurement	supine sitting standing moving not mentioned	116 (25.4) 194 (42.5) 4 (0.9) 3 (0.7) 140 (30.6)	--	HRV dependence on subjects' posture.
Artefact clean-up	yes no/ not mentioned	216 (47.2) 241 (52.8)	--	Post-processing by means of visual inspection and manual editing.

Notes. AR = Autoregressive Algorithm; ECG = electrocardiogram; FFT = Fast Fourier Transform; HF = high frequency power; HRV = heart rate variability; IBI = interbeat interval; LF = low frequency power; PPG = photoplethysmograph; TFG = Task Force guidelines.

[a] Only the three most frequent characteristics are specified. [b] If a fixed number of IBIs had been analysed, the length of the analysis interval was coded as not applicable and vice versa.

2.3.3. Presentation and Interpretation of Results

To characterize the HRV in psychological short-term measurements various parameters can and should be used. Remember, the TFG (Task Force, 1996) recommend the calculation and documentation of time domain parameters (SDNN, rMSSD, and pNN50) and frequency domain parameters (HF and LF in absolute and relative units, TP, and LF/HF). Additionally, we will consider the CV, as this index provides less dependence on heart rate. It follows that we subsequently give priority to the reported heart rate, time domain, and frequency domain parameters. The reporting frequency of these various parameters depends to a large extent on whether or not the studies make explicit reference to the TFG. Note, therefore, that the following percentages refer to one of these groups: total sample (N = 457), studies referring to TFG (n = 298), and studies without reference to TFG (n = 159). We will note the reference group in each case. Figure 7 shows the reporting rates for all considered heart rate, time domain, and frequency domain parameters.

2.3.3.1. Heart Rate and Interbeat Interval

The mean heart rate is reported in 59.3 % (n = 271) of all studies. The reporting rate differences between studies referring to the TFG (n = 180, 60.4 %) and those with no reference to these guidelines (n = 91, 57.0 %) are small. A considerably smaller amount of studies reports the mean IBI, with 19.7 % (n = 90) of all studies. Again, the differences depending on the TFG reference are small. Heart rate or IBI are easy to calculate if one of these two parameters is given. 70.2 % (n = 320) of all articles report at least one of these parameters.

2.3.3.2. Statistical Time Domain Parameters

The most common time domain parameter is rMSSD, which is reported in 30.9 % (n = 141) of all studies. Here we can state a distinct difference between our two groups (reference to TFG: n = 104, 34.9 %; no reference to TFG: n = 37, 23.3 %). On the other hand, the variable CV is used only very rarely (3.5 % in total, *n* = 16). SDNN is reported in about every fifth study (*n* = 101; 22.1 %), pNN50 in 7.7 % (*n* = 35) of all articles.

2.3.3.3. Frequency Domain Parameters

The most frequently reported parameter HF is given by 78.5 % (*n* = 234) of all studies making reference to the TFG, and for 50.3 % (*n* = 80) of studies not referring to the TFG. The overall reporting rate is for HF 68.7 % (*n* = 314) and for LF 51.4 % (*n* = 235). The use of normalized units depends strongly on whether the studies refer to the TFG. Only a very small proportion of studies that do not relate to the TFG report these parameters (HF nu: *n* = 10, 6.3 %; LF nu: *n* = 4, 2.5 %). In contrast, studies referring to the guidelines report these parameters more often (HF nu: *n* = 68, 22.8 %; LF nu: *n* = 65, 21.8 %). The use of VLF is not recommended by the TFG for short-term recordings (≤ five minutes). Nevertheless, we find that this parameter is reported for 10.5 % (*n* = 48) of all studies, and for 10.3 % (*n* = 28) of studies with an analysis interval of five minutes or less (*n* = 271).

It is striking that the just mentioned difference between reference and no reference to the TFG is evident for almost all parameters. These differences are statistically significant for HF, HF nu, LF, LF nu, LF/HF, and TP, χ^2 (1) ≥ 17.62, $p < .001$, $196 \leq \phi \leq .290$, as well as for rMSSD, χ^2 (1) = 6.57, $p = .011$, $\phi = .120$. Effect sizes can be considered as small (J. Cohen, 1988). 61 studies (13.3 %) used additional geometric or nonlinear analysis methods, such as Poincaré plot analyses or entropy-based methods. The lack of uniform standard values is reflected in the interpretation of results. The vast majority of studies compare their data within their sample (e.g., pre vs. post, experimental group vs. control group), without using external criteria (such as normal values).

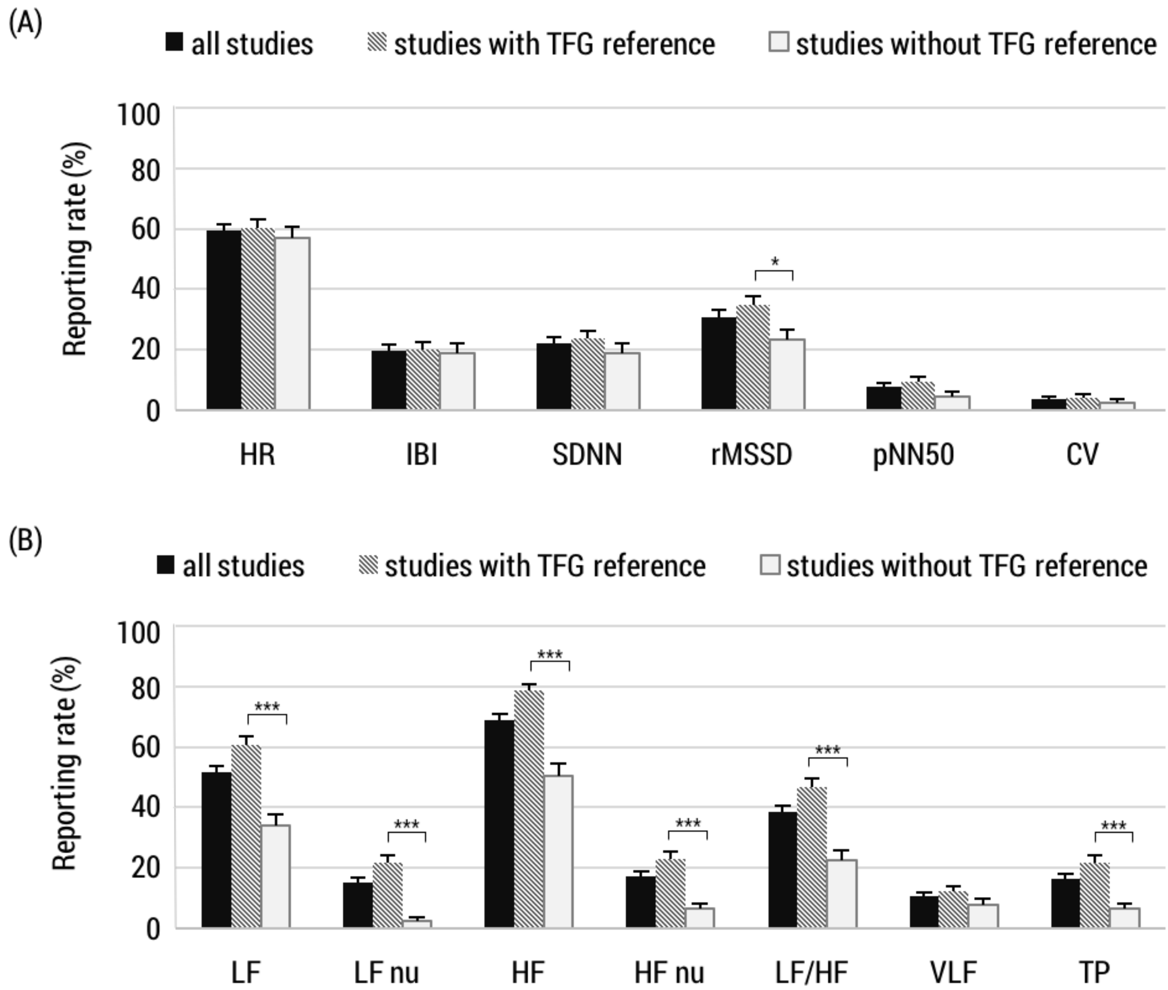


Figure 7. Percentage of studies reporting the respective parameter depending on their reference to the TFG (Task Force, 1996) and in total (with reference: n = 298, without reference: n = 159, total: N = 457). Reporting rates are compared with respect to TFG reference/ no reference. Bars indicate associated standard errors. (A) Heart rate and statistical time domain parameters. (B) Frequency domain parameters. Note that LF/HF includes two cases of HF/LF. CV = coefficient of variation of IBIs, HF = high frequency, HF nu = normalized units of HF, HR = (mean) heart rate, IBI = (mean) interbeat interval, LF = low frequency, LF nu = normalized units of LF, LF/HF = ratio of HF and LF, pNN50 = percentage of successive IBIs with a difference > 50 ms, rMSSD = square root of the mean squared differences of consecutive IBIs, SDNN = standard deviation of IBIs, TFG = Task Force guidelines, TP = total power, VLF = very low frequency.

* p < .05, *** p < .001.

2.3.3.4. Number of Reported Parameters

How many of the HRV parameters for short-term measurements recommended by the TFG are actually reported in the respective studies? Our analyses of this question include SDNN, rMSSD, and pNN50 as time domain parameters, and HF, LF, LF/HF, and TP as frequency parameters.

Note that we do not distinguish at this point whether HF and LF are given as absolute or relative values. On average, each study reports $M = 0.61$ ($SD = 0.83$; $Mdn = 0$) time domain parameters and $M = 1.74$ ($SD = 1.30$; $Mdn = 2$) frequency domain parameters. That means, in total $M = 2.35$ ($SD = 1.64$; $Mdn = 2$) out of seven recommended parameters are described. When considering all seven recommended parameters, only nine studies (2.0 %) report all of them. In contrast, 40 articles (8.8 %) do not report any of these recommended parameters. In these studies, the authors often used either pure heart rate parameters (such as heart rate, mean IBI) or other indicators to evaluate the HRV (e.g., standard deviation of heart rate, VLF, mid frequency band, nonlinear metrics). As indicated by Table 7, significant differences emerge between those studies referring to the TFG (time domain: $Mdn = 0$, frequency domain: $Mdn = 2$, total: $Mdn = 3$) and those not mentioning these recommendations (time domain: $Mdn = 0$, frequency domain: $Mdn = 1$, total: $Mdn = 1$), with $U = 20782$, $z = -2.44$, $p = .015$, $r = -.11$ (time domain); $U = 13908$, $z = -7.46$, $p < .001$, $r = -.35$ (frequency domain); $U = 13529$, $z = -7.74$, $p < .001$, $r = -.36$ (total). Effects can be considered as small (time domain) and medium (frequency domain and total; J. Cohen, 1988).

Interestingly, articles referring to the TFG ($Mdn_{cpd} = 2.83$, $Mdn_{SJR} = 1.10$) are not published in higher impact journals as those not referring to the TFG ($Mdn_{cpd} = 2.76$, $Mdn_{SJR} = 1.11$; cpd 2y: $U = 21256$, $z = -1.23$, $p = .220$, $r = -.06$; SJR: $U = 22303$, $z = -0.43$, $p = .670$, $r = -.02$). Therefore, let us now take a closer look at the interrelations between methodological characteristics and indicators of “scientific success”.

Table 7

Number of Reported HRV Parameters Recommended by the TFG (Task Force, 1996) Depending on the TFG Reference of the Studies

Number of reported parameters	All studies (*N* = 457)	Studies with TFG reference (*n* = 298)	Studies without TFG reference (*n* = 159)
	Frequency (%)	Frequency (%)	Frequency (%)
	Time domain parameters		
0	262 (57.3)	161 (54.0)	101 (63.5)
1	134 (29.3)	87 (29.2)	47 (29.6)
2	40 (8.8)	34 (11.4)	6 (3.8)
3	21 (4.6)	16 (5.4)	5 (3.1)
	Frequency domain parameters		
0	101 (22.1)	37 (12.4)	64 (40.3)
1	112 (24.5)	72 (24.2)	40 (25.2)
2	91 (19.9)	61 (20.5)	30 (18.9)
3	110 (24.1)	89 (29.9)	21 (13.2)
4	43 (9.4)	39 (13.1)	4 (2.5)
	Time and frequency domain parameters		
0	40 (8.8)	10 (3.4)	30 (18.9)
1	142 (31.1)	76 (25.5)	66 (41.5)
2	79 (17.3)	52 (17.4)	27 (17.0)
3	89 (19.5)	65 (21.8)	24 (15.1)
4	59 (12.9)	53 (17.8)	6 (3.8)
5	27 (5.9)	26 (8.7)	1 (0.6)
6	12 (2.6)	9 (3.0)	3 (1.9)
7	9 (2.0)	7 (2.3)	2 (1.3)

Notes. According to the recommendations of the TFG a maximum of three time domain and four frequency domain parameters can be reported. Frequencies and percentages vary depending on the TFG reference of the studies. HRV = heart rate variability; TFG = Task Force guidelines.

2.3.4. HRV Parameters and Scientific Success

The hypothesis that there are positive correlations between methodological qualities (i.e., the number of reported parameters) and scientific success (in terms of impact factor; SJR, cpd 2y) is not confirmed. For SJR even small negative correlations emerge (time domain: r_s = -.11 p = .015; frequency domain: r_s = -.09, p = .064; total: r_s = -.12, p = .010). Moreover, we observe no indications of a temporal trend in this respect, as publication year and number of reported parameters are entirely uncorrelated. However, there are positive correlations between impact factors and sample size, with r_s = .14, p = .003 (correlations are identical for both impact factors). Finally, number of reported frequency domain parameters increases with the selected analysis interval, with r_s = .19, p < .001.

2.4. Discussion and Recommendations

The aim of our review was to provide an overview of the methodological status quo of HRV short-term measurements in human adults. Our results confirm and extend the implications of other authors (e.g., see de Vries, 2013; Ellis et al., 2015; Koenig et al., 2016; Nunan et al., 2010; Quintana & Heathers, 2014; Schneider, 2015; Tak et al., 2009; Zahn et al., 2016): First of all, although specific guidelines (Task Force, 1996) have been proposed two decades ago, and although HRV research continues to increase considerably since then, we are still far from establishing HRV measurement as a well-standardized methodological procedure. Based on our results, we will present specific recommendations for short-term HRV measurements under resting conditions. Finally, we will discuss the limitations of this review.

2.4.1. Sample Characteristics

Although a detailed description of the studied sample is a central requirement in scientific research, clear indicators of sample age (either by mean or median) have not been reported in 40 studies (8.8 %). In most of these studies the authors report age ranges or rather vague clues to the age group (such as students or older adults). However, as age has a strong influence on HRV magnitudes (e.g., Abhishekh et al., 2013; Agelink et al., 2001; Almeida-Santos et al., 2016; Antelmi et al., 2004; Eller-Berndl, 2015; Voss et al., 2015; Zhang, 2007), an accurate indication of sample age is clearly needed. The same is true for the specification of the participants' gender. Given the evident main effects of gender and the interaction effects of gender and age on HRV (e.g., Antelmi et al., 2004; Eller-Berndl, 2015; Fagard et al., 1999; Koenig & Thayer, 2016; Voss et al., 2015; Young & Leicht, 2011), the exact gender composition of the sample and each experimental group or condition constitutes an important statistic in the context of HRV measurements. 434 (95.0 %) of the reviewed studies have done that, though, gender-specific HRV values have been reported rarely.

Within our selection of studies, sample sizes vary considerably. For 31.1 % (*n* = 142) of studies, samples are smaller than *N* = 30. One might argue that this is not necessarily a methodical deficit, because small samples might be sufficient for specific research questions. However, studies with this small sample sizes are not suited for the calculation of norm values (see Nunan et al., 2010, for a discussion of this point). Generally, larger samples are beneficial for most research questions, as they avoid power insufficiencies (J. Cohen, 1988) and are more suitable for attempts to classify and systematize.

2.4.2. Basic Characteristics of HRV Data Collection

2.4.2.1. Treatment of Respiration Effects

With respect to the substantial respiration effects on HRV, 269 (58.9 %) studies provide no exact information regarding the control or specification of respiration. Considering the respiratory influences on HRV and the ongoing discussion on how to handle these dependences (e.g., see Allen et al., 2007; Berntson et al., 1997; Denver et al., 2007; Grossman et al., 1991; Grossman & Taylor, 2007; Hirsch & Bishop, 1981; Ritz, 2009; Ritz et al., 2001), that is a highly unfavourable state of affairs. Given the current disagreement concerning treatment of respiration effects and in accordance with others (Allen et al., 2007; de Vries, 2013; Denver et al., 2007; Houtveen et al., 2002), we recommend that investigators instruct their participants to breathe normally, thus enabling researchers to investigate the spontaneous and as normal as possible activity of the organism. This recommendation is supported by the results of Kobayashi (2009), revealing that paced breathing improves the reproducibility of HRV parameters only marginally (see also Pinna et al., 2007). At the same time, researchers are well-advised to ensure that participants breathe in the high frequency range (about nine to 24 respiratory cycles per minute; Allen et al., 2007; Berntson et al., 1997; de Vries, 2013). Additionally, attention should be paid to other factors influencing respiration (such as immediate physical activity prior to the measurement), in order to minimize the likelihood of undesired respiration effects (e.g., varying breathing rates between experimental conditions or groups; Allen et al., 2007; Grossman & Taylor, 2007). One way or another, all breathing-related details of the study should be described with great care.

2.4.2.2. Daytime of Measurement

The percentage of studies giving no information concerning daytime of measurements is very high (*n* = 285, 62.4 %), especially when considering the circadian influences on HRV (see, for example, Bilan et al., 2005; Boudreau et al., 2012; Eller-Berndl, 2015; Guo & Stein, 2002; Huikuri et al., 1990; Pumprla et al., 2002). Note, however, circadian rhythms are known to be highly individual (Refinetti, 2016), complicating the investigation of circadian HRV patterns. Notwithstanding, we recommend to note and report the daytime of measurements. This will help to analyse the impact of daytime on one's own data. In addition, this kind of information becomes available to other researchers interested in meta-analyses or norm value calculations. Finally, great care should be taken that the study design does not encourage systematic daytime differences between various experimental conditions, groups, or repeated measurements (see also Allen et al., 2007).

2.4.2.3. Recording and Analysis Interval

There is wide range of recording and analysis intervals that are actually used by researchers. This may have several reasons. First, the design of a study can be associated with different HRV recording intervals (e.g., subjects had to complete different tasks while ECG was recorded). Second, the TFG (1996) did not distinguish clearly between recording and analysis interval. This might have contributed to some confusion (although the TFG offered recommendations regarding the interval length, see Table 6). Many researchers refer to the distinction provided by the TFG (i.e., short-term measurements = five minutes, long-term measurements = 24 hours). Of course, many gradations between these two extreme specifications are possible (e.g., sometimes, all intervals up to 60 minutes are regarded as short-term measurements; see Sammito et al., 2015). Within our sample, there are six studies with analysis intervals of 60 minutes each. Hence, it is difficult to classify these studies straightforwardly as either short-term or long-term measurements.

Most importantly, the selected analysis interval is crucial for the calculation and comparability of HRV parameters. For example, SDNN is strongly influenced by the length of the analysed interval (Allen et al., 2007; Task Force, 1996). Our results show that a five-minute analysis interval is most frequently used (total sample: n = 173, 37.9 %; for studies referring to the TFG: n = 127, 42.6 %). However, the majority of researchers has chosen either other durations, or even a fixed number of IBIs. The heterogeneity of this methodological characteristic creates an enormous problem with respect to the comparability of HRV parameters.

As a solution, we recommend a standardized analysis interval of five minutes, and a recording interval of at least eight minutes. Eight minutes is a good advice, because the extra time increases the likelihood that researchers will be able find a five-minute analysis interval that is free from artefacts. At the same time, the procedure still remains economical. Moreover, our own experience suggests that the participants often need some time for physical regulation at the beginning of the study. This is especially true if participants were active immediately prior to the measurement (e.g., de Vries, 2013; Grossman & Taylor, 2007; Tortora & Derrickson, 2006; Valentini & Parati, 2009); in such cases, the heart rate will be higher at the beginning of recording. When considering the data from the present review, analysis interval and recording interval have been identical in 255 studies (55.8 %), thus employing a procedure that contains several risks and impediments.

Finally, an alternative that has sometimes been used is the analysis of a fixed number of IBIs (e.g., Carter, Banister, & Blaber, 2003; Druschky et al., 2001; Grimaldi et al., 2010; Kunz et al., 2012; Riganello, Candelieri, Quintieri, Conforti, & Dolce, 2010). Of course, this is an interesting approach in terms of comparability within a study (i.e., the number of IBIs is the same for all subjects, independent of their heart rate). However, our data suggest that there is no consensus on the number of intervals to be analysed and therefore comparability between studies is limited again. Despite the standardization lack of short-term HRV measurements, other researchers already investigating the usability of ultra-short-term recordings as alternative to the usual five-minute analyses (for example, see Baek, Cho, Cho, & Woo, 2015; Muñoz et al., 2015; Nussinovitch et al., 2011; Nussinovitch, Cohen, Kaminer, Ilani, & Nussinovitch, 2012); with partly heterogeneous results regarding suitable HRV parameters and necessary analysis interval lengths.

2.4.2.4. Measuring Instruments, Sampling Rates, and Spectral Analysis

The vast majority of studies has used an ECG for recording cardiac activity, which is in line with the TFG (Task Force, 1996). Also, the reported sampling rates correspond largely to the TFG, or even surpass them in most cases. However, with respect to technical developments in recent years, a sampling rate of 1000 Hz seems to be the new benchmark (Sammito et al., 2015).

Although the use of a classical ECG is regarded as gold standard (Sammito & Böckelmann, 2016; Task Force, 1996; Zahn et al., 2016), technological progress seems to offer additional options such as the use of different kinds of mobile devices (e.g., wrist worn devices or chest belts). Meanwhile, there are several studies that have analysed some of these devices. In summary, results suggest that mobile devices are quite useful under certain experimental conditions (above all, during rest) and for certain HRV parameters (e.g., Hayano, Barros, Kamiya, Ohte, & Yasuma, 2005; Parak et al., 2015; Sammito & Böckelmann, 2016; Schäfer & Vagedes, 2013; Weinschenk, Beise, & Lorenz, 2016). Typical problems associated with mobile devices are the overestimation of parasympathetic parameters (e.g., HF, RMSSD) and the growing inaccuracy of PPG/mobile measurements with increasing subjects' activity (Charlot et al., 2009; de Vries, 2013; Schäfer & Vagedes, 2013; Weinschenk et al., 2016). We conclude that the mobility and flexibility of these devices is especially attractive when it comes to studying HRV characteristics outside the laboratory. Nevertheless, a classic ECG still delivers the highest accuracy of data (Schäfer & Vagedes, 2013) and should thus be used whenever possible.

Although the TFG (1996) did not determine the method for spectral analysis, it had been recommended to specify the transformation method and (depending on the method) further parameters. Given these recommendations, it is problematic that 29.4 % (*n* = 105) of all studies that do report at least one frequency domain parameter (such as HF, LF; *n* = 357) fail to give information concerning the method of calculation. Regardless of the method used, a detailed description of the spectral analysis that has been carried out is highly advisable. For example, note that the two most prominent methods, FFT and AR (taken together, these two procedures have been used in more than 50 % of the reviewed studies), are highly correlated (Hayano et al., 1991), although produced values are hardly comparable (see Chemla et al., 2005; Ohara et al., 2016; Pichon et al., 2006). To put it simply: Norm values for spectral components have to be specified for each power spectrum analysis method.

2.4.2.5. Substance Influences

The control or identification of subjects' medication and consumption behaviour (caffeine, nicotine, alcohol) is reported in about half of the studies. As these substances are known to exert notable influences on current HRV indices (e.g., Acharya et al., 2006; Aronson & Burger, 2001; de Vries, 2013; Dinas et al., 2013; Eller-Berndl, 2015; Flanagan et al., 2002; Hayano et al., 1990; Licht et al., 2008; O'Regan et al., 2015; Rauh et al., 2006; Richardson et al., 2004), researchers should do their best to detect their use, at least via questionnaire. In addition, uniform and standardized exclusion criteria are clearly needed.

2.4.2.6. Activity prior and during Measurement and Posture

Although these variables constitute basic study features and mechanisms influencing the biological system and thus HRV, our results suggest a high degree of missing information as well as heterogeneous methodology. Control or identification of immediate activity of participants is mentioned only by 43.5 % (n = 199) of studies, though physical activity and heavy meals proximally influence heart rate and HRV (e.g., Lu et al., 1999; Quintana & Heathers, 2014; Tak et al., 2009; Valentini & Parati, 2009). In line with other authors (Quintana & Heathers, 2014; Tak et al., 2009), we recommend to instruct participants to avoid heavy activity and meals at least two hours prior to the measurement. Additionally, upon subjects' arrival at the laboratory, some time for physiological acclimatization before recording HRV should be scheduled. The activity of the subject during measurement is also important, as heart rate increases and HRV decreases with physical activity (de Vries, 2013; Grossman & Taylor, 2007; Tortora & Derrickson, 2006). While the majority of studies examined HRV under resting conditions (*n* = 331, 72.4 %), posture methodology is quite diverse: In 42.5 % (*n* = 194) of all studies, HRV has been recorded while subjects were seated. In contrast, 25.4 % (*n* = 116) of articles describe measurements with supine subjects. Due to the strong influence of posture and associated changes in sympathetic and parasympathetic activity (e.g., Acharya et al., 2005; Cipryan & Litschmannova, 2013; Dietrich et al., 2010; Grossman & Taylor, 2007; Kowalewski & Urban, 2004; Mahananto et al., 2015; Radhakrishna et al., 2000; Task Force, 1996; Vuksanovic et al., 2005), we recommend to perform HRV measurements with supine participants. In addition, participants should be advised to move as little as possible (de Vries, 2013). In supine position, a high level of (muscle) relaxation can be expected. Thus, the likelihood of involuntarily muscle contractions and random movements is reduced (Houghton & Gray, 2001).

2.4.2.7. Removal of Artefacts

Although artefact clean-up is explicitly reported only in 47.2 % (*n* = 216) of the studies, we can assume that post processing of recorded IBI series has been performed in considerably more studies. This careful inspection and post editing of ECG recordings is an essential and necessary task to obtain reliable and exact HRV parameters (especially in the frequency domain; Berntson et al., 1997; de Vries, 2013; Task Force, 1996). For this purpose, different methods are available depending on the used software (Jarrin, McGrath, Giovanniello, Poirier, & Lambert, 2012). Unfortunately, we are not able to provide a more specific analysis of the applied artefact processing methods due to the lack of information in this regard. A visual inspection and manual editing of the entire IBI time series had been recommended by the TFG (1996) and should be preferred to automated approaches, although manual cleaning is very laborious (Berntson et al., 1997). Ideally, an artefact free five-minute interval is selected from a larger recording interval. If no artefact free five-minute interval is present, researchers are well-advised to manually edit data (e.g., ectopic beats), for example by adding missed beats or by removing mistakenly detected peaks (de Vries, 2013). A combination of visual inspection and automated clean-up as well as proper interpolation/regression methods are also conceivable (Berntson et al., 1997; Jarrin et al., 2012; K. K. Kim, Kim, Lim, & Park, 2009; Task Force, 1996). In the interest of artefact prevention, signal and subject should be observed throughout the entire measurement; hence, motion artefacts can be identified and marked for post processing (de Vries, 2013). Anyway, researchers should clearly document and report their specific procedures for data editing (Jarrin et al., 2012).

2.4.3. Presentation of Results

When analysing the reporting of heart rate and HRV parameters, huge differences become apparent. The reporting rates vary both between the respective parameters, as well as between studies with and without TFG reference; although our coding was very generous. As noted, we counted a parameter as being reported when it was evaluated in the results section in any form (e.g., as raw value, logarithmic value, in correlative or inferential statistical contexts, represented in figures, etc.). This procedure likely overestimates the amount of helpful data (e.g., for meta-analyses or systematic reviews).

2.4.3.1. Heart Rate and Interbeat Interval

70.2 % (*n* = 320) of studies meet the recommendation to indicate the heart rate levels or the average IBI, as a basis for interpretation and standardization of other HRV parameters (see for example, Grossman & Taylor, 2007; Sacha, 2013, 2014; Sacha, Barabach, et al., 2013). For these variables, it makes no difference whether researchers refer to the TFG or not (contrary to our findings for almost all other variables). Of course, reporting of at least one of these two parameters is highly advisable. Ideally, both variables are reported in the form of non-transformed raw values.

2.4.3.2. Statistical Time Domain Parameters

Time domain parameters are reported significantly less as compared to frequency domain parameters. Among other reasons, this might be due to the fact that spectral parameters are regarded as being more proper in the context of short-term measurements (Task Force, 1996). Within the time domain parameters, rMSSD is by far the most commonly reported one (in total: *n* = 141, 30.9 %; reference to TFG: *n* = 104, 34.9 %; no reference to TFG: *n* = 37, 23.3 %). Possible reasons for this result are the unambiguous interpretability of rMSSD (i.e., as indicator for vagal activity) and the TFG (1996) recommendation that rMSSD is preferable as compared to pNN50 (see also Hallman et al., 2015; Shaffer et al., 2014). We recommend that all common short-term time domain parameters and a relative value (such as CV) should be reported (before and after log-transformation). This is because CV is more likely to offer the opportunity to compare results from different studies and to counteract the mathematical bias already mentioned (see Booij et al., 2006; Ikawa et al., 2001; Nunan et al., 2010; Sacha, 2013; Sacha, Barabach, et al., 2013; Sacha & Pluta, 2005, 2008). Additionally, standardization of HRV parameters with respect to the heart rate (IBI respectively) tends to improve the reproducibility of HRV measurements (Sacha, 2014; Sacha, Sobon, Sacha, & Barabach, 2013).

2.4.3.3. Frequency Domain Parameters

The range of variation for reporting frequency parameters is astounding. While HF is the most frequently reported HRV parameter (total: *n* = 314, 68.7 %), LF nu (total: *n* = 69, 15.1 %) and VLF are only rarely reported (total: *n* = 48, 10.5 %). For VLF, this is not surprising given its low suitability for short-term measurements (Berntson et al., 1997; Shaffer et al., 2014; Task Force, 1996). The frequent use of HF is likely based on the clear recommendation of the TFG and the good interpretability of this parameter (similar to rMSSD; Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; de Vries, 2013; Eller-Berndl, 2015; Pumprla et al., 2002; Shaffer et al., 2014). In contrast, LF and LF/HF are quite difficult to interpret (for example, see Berntson et al., 1997; Billman, 2013; Cygankiewicz & Zareba, 2013; Eckberg, 1997; Eller-Berndl, 2015; Goldstein et al., 2011; Heathers, 2014; Shaffer et al., 2014). Note the large differences depending on the TFG reference (especially for HF nu, LF nu, and TP). Except for VLF, all the differences between reference- and no reference-group are significant, which suggests the (positive) influence of the TFG on parameter reporting.

2.4.3.4. Geometric and Nonlinear Analyses

The rare use of geometric or nonlinear methods (*n* = 61, 13.3 %) might be due to the lack of recommendations in this area as well as due to the unsuitability of geometric techniques for short-term HRV (Task Force, 1996). Further, nonlinear analyses are highly complex, mathematically challenging (for example, see Cygankiewicz & Zareba, 2013), and partly vulnerable to artefacts (Sammito & Böckelmann, 2015). Also, it seems to be likely that they are typically not integrated into conventional HRV software systems, although many authors emphasize the high potential of these methods, especially vis-à-vis the superior fit of nonlinear methods to the complex origin of the heartbeat (e.g., see Acharya et al., 2014; Cygankiewicz & Zareba, 2013; Goldberger, 1990; Hoshi et al., 2013; Huikuri et al., 2003; D. T. Kaplan et al., 1991; Kleiger et al., 2005; Quintana & Heathers, 2014; Sammito & Böckelmann, 2015).

2.4.3.5. Number of Reported Parameters

Two results are interesting in this vein: First, the overall number of reported parameters is not particularly high. 76.6 % (*n* = 350) of the studies report a maximum of three out of seven time and frequency domain parameters. This means that about three quarters of all studies report less than 50 % of the recommended parameters. Surprisingly, only nine studies (2.0 %) report all seven parameters. Second, there are again significant differences depending on the TFG reference, above all in terms of the number of reported frequency parameters.

2.4.4. HRV Parameters and Scientific Success

Our assumption that the number of reported HRV parameters tends to be higher for studies published in journals with higher impact factors has not been confirmed. Strictly speaking, the impact factor is “only” a measure of the average quantity of citations regarding all citable items of a journal within a given period of time, and not a measure of methodological quality (or the quality of individual authors/articles, peer review processes, journal content; e.g., Garfield, 1972; Jones et al., 2011; Scully & Lodge, 2005; Seglen, 1997; M. Sharma, Sarin, Gupta, Sachdeva, & Desai, 2014). Accordingly, Tressoldi, Giofré, Sella, and Cumming (2013) argue that it is not the impact factor of a journal, but rather editorial policy and mandatory guidelines that influence the quality of published research. Furthermore, the impact factor of a journal is largely dependent upon the field of research, number of self-citations, type of published studies (e.g., reviews or meta-analyses), accessibility of the journal, and several other factors (Scully & Lodge, 2005;

Seglen, 1997). Moreover, the number of article citations differs enormously within a journal, that is, a relatively small proportion of articles is often responsible for a large percentage of citations (P. Campbell, 2008; Seglen, 1997). Considering these arguments, our results are not really surprising.

2.4.5. Methodological Guidelines versus Empirical Heterogeneity

One basic result of the present review is the huge heterogeneity of methodological standards in HRV research, together with a large amount of missing information for many variables, as is the case for respiratory control, control of various substance influences, participants' posture, analysis interval, post editing of data, and parameter calculation as well as reporting. There are only a few variables that are characterized by a broad consensus to previous recommendations: This is the case for the type of measuring devices used and the underlying sampling rates. Both variables obviously benefit from technical progress in these domains. In general, however, the field is severely handicapped by the fact that existing multitude of different HRV studies is still not really comparable; therefore, data interpretation is difficult not only for single studies, but even more so across multiple studies.

On the positive side, studies citing the TFG from 1996 tend to conform to these recommendations to a higher degree. Therefore, a positive impact of such guidelines on published HRV literature becomes apparent. Nevertheless, even among those studies citing these guidelines, considerable methodological variety exists. This raises the question whether the TFG can be referred to as a generally accepted standard.

We conclude that the present situation requires further standardization and improvement. As a consequence, we have summarized all our recommendations for HRV short-term measurements (more specific: for baseline measurements at rest) in Figure 8 (for a first attempt hereto, see de Vries, 2013). This overview can certainly be understood as an extract of our comprehensive debate on this field of research and adheres, of course, to the TFG (Task Force, 1996). Above all, researchers, who just become acquainted with the current standards in the field of HRV research, should be able to benefit from this to a higher degree. In this light, we consider our recommendations as a *checklist for psychologists*.

1

Sample Requirements and Recommendations

- ✓ **Sample Size**: Ensure an appropriate sample size with respect to research question and study design.
- ✓ **Sample Characteristics:** Assess and report participants' substance consumption (medication, alcohol, caffeine, nicotine) and subject variables (age, gender, BMI, health status, fitness level).
- ✓ **Participants' Instruction**: Instruct participants to avoid excessive activity, heavy meals, and luxury food (nicotine, caffeine, alcohol) at least two hours prior to the measurement; Instruct participants to move as little as possible during measurement.

2

Planning your Measurement

- ✓ **Time of Day**: Invite participants at times of similar activity; Randomly assign subjects to different daytimes; Note and report daytime of measurements.
- ✓ **Device and Software**: Preferably use an ECG with a sampling rate of at least 500 Hz; Choose a method for spectral analysis and report the applied method in detail (e.g., cut-off values of spectral components).
- ✓ **Spatial Conditions**: Prefer ECG recordings on supine subjects, alternatively, provide a comfortable seat; Ensure a comfortable temperature (about 22°C) and a quite environment.

3

Running your Measurement

- ✓ **Acclimatisation**: Encourage the physical regulation of participants by granting some time prior to the measurement.
- ✓ **Respiration**: Instruct participants to breathe normally; Ensure that respiration rates are in accordance with the high frequency range (9-24 cycles per minute); If not, adjust the cut-off values of the frequency bands.
- ✓ **Signal Verification**: Ensure that R peaks are well recognizable; Observe the signal and the participant during the entire recording.
- ✓ **Recording and Analysis Interval**: Choose at least eight minutes for recording and extract five minutes to analyse.

4

Post Processing and Reporting

- ✓ **Removal of Artefacts**: Visual inspection and manual editing of the entire IBI time series; Report your procedure in detail.
- ✓ **Heart Rate and IBI**: Report mean IBI and heart rate of your experimental groups/conditions.
- ✓ **Time Domain**: Report SDNN, rMSSD (optionally pNN50), and CV as non-transformed and logarithmic values.
- ✓ **Frequency Domain**: Report TP, HF, HF nu, LF, LF nu, and LF/HF as non-transformed and logarithmic values.
- ✓ **Further Parameters**: Report all further analyses, such as geometric or nonlinear approaches.

5

General Recommendations

- ✓ **Reporting**: If you are forced to shorten your manuscript, provide additional information regarding your method and the computed parameters as appendix. Alternatively, deposit these information in a public repository and specify the corresponding reference within your manuscript.
- ✓ **Between-Subjects Design**: Ensure that experimental conditions or groups do not differ with respect to the above mentioned characteristics (e.g., age, gender, respiratory rates, activity prior to the measurement).

Effects of Recommendations

Interpretability: The interpretability of computed HRV parameters (especially vagal associated indices) is encouraged.

Comparability: The better your procedure is standardized and reported, the better different studies are comparable.

Usability: The usability of your data for the generation of norm values or for meta-analyses increases.

Figure 8. Review recommendations for HRV short-term measurements under resting conditions. BMI = body mass index; CV = coefficient of variation of IBIs; ECG = electrocardiogram; HF = high frequency power; HF nu = normalized units of HF; HRV = heart rate variability; IBI = interbeat interval; LF = low frequency power; LF nu = normalized units of LF; LF/HF = ratio LF and HF; pNN50 = percentage of successive IBIs with a difference > 50 ms; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TFG = Task Force guidelines; TP = total power.

2.4.6. Potential Reasons for Heterogeneity and Non-Reporting

A significant improvement of the current state of affairs requires a careful analysis of its causes. In our opinion, there are different reasons for methodological heterogeneity of HRV studies already mentioned by other authors (e.g., see Bürklein, Vogt, & Banzer, 2005; de Vries, 2013; Ellis et al., 2015; Jarrin et al., 2012; Koenig et al., 2016; Nunan et al., 2010; Quintana & Heathers, 2014; Schneider, 2015; Tak et al., 2009; Zahn et al., 2016). One reason could be that the TFG from 1996 are perceived as outdated (e.g., due to technological progress), are not known by some authors or editors, or are not clear enough (e.g., the distinction between analysis and recording interval or the recommended method of spectral analysis; de Vries, 2013). As a consequence, these guidelines should be urgently revived, updated, and supplemented (cf. Bürklein et al., 2005; Nunan et al., 2010). This also implies that the respective researchers and editors have to deal with these guidelines and standards.

Of course, lack of knowledge of researchers, inadequate equipment (e.g., no possibility of measurements of supine participants, no conventional ECG, inappropriate HRV software not calculating all recommended HRV parameters), or specific study designs (e.g., no baseline measurement) can also lead to methodological diversity. Perhaps, in some issues, not all HRV parameters are of interest, for example, if only vagal influences on HRV are investigated (this is also related to the inconsistent interpretation of HRV parameters). Possibly even the often-cited distribution problems of several parameters (e.g., see Dietrich et al., 2010; Hallman et al., 2015; Pinna et al., 2007) are responsible for selective use or reporting. Another reason for non-reporting important information could be that some authors refer in their methods description to other studies ("described elsewhere"), resulting in a lack of details to several methodological aspects (as you can see by Booij et al., 2006; Fujibayashi et al., 2009; Guinjoan et al., 2007), as we did not follow these references in the context of our coding. Again, comprehensive, understandable, and binding guidelines can provide a solution.

As became apparent by now, the research on HRV increases dramatically (see Figure 1), and it is not easy to oversee the relevant literature. Moreover, an extensive know-how is needed to apply the relevant methods and analysis techniques appropriately. Interdisciplinary teams (e.g., physicians, psychologists, mathematicians, computer scientists) are needed in this context. However, it is also clear that such basic conditions do not always exist.

Publication biases might contribute to inconsistent reporting of recommended HRV parameters (see Tak et al., 2009; Zahn et al., 2016). A preference for submitting and publishing significant results (see Easterbrook, Gopalan, Berlin, & Matthews, 1991; Franco, Malhotra, & Simonovits, 2014; Rosenthal, 1979; Sterling, 1959) might motivate researchers to report only those HRV parameters, which are in line with hypothesis or which vary significantly. Tressoldi and colleagues (2013) argue that editorial and journal policies exert a strong impact on reviewing und publishing processes. For example, authors might be forced to shorten their manuscripts, leading to a loss of information. To further explore these considerations, one would need to compare original submitted manuscripts with corresponding published articles. In sum, further research is needed to investigate the causes for the current data situation in detail.

2.4.7. Limitations

We would like to mention the limitations regarding our method and our results. One problem is finding an appropriate global search term (in our case: *heart rate variability*). A measurement of HRV has not been the primary focus of all studies we found. Sometimes, HRV is a by-product of the actual research question (see, for example, Abrams et al., 2011). This might be a reason for describing the HRV methodology only rather scarcely.

Similar arguments also apply to the extremely elaborate study selection process (see Figure 4). We may have tried simplifying this process by using more specific search terms (e.g., *heart rate variability* in combination with *short-term*). However, in doing so, relevant studies might have been excluded, as for example studies using comparatively long analysis intervals. Note that, given the selection strategy we pursued, our results are especially valid for psychological studies using short-term measurements.

Another aspect of data collection is worth mentioning here. The coding of the studies was quite difficult, especially due to inconsistencies in terminology and study description. The HF parameter is a telling example in this vein: Some authors refer to this as RSA (e.g., Oveis et al., 2009) or vagal tone (e.g., Aboussafy, Campbell, Lavoie, Aboud, & Ditto, 2005). However, the term RSA is also used ambiguously, and some authors regard RSA as "the difference between the minimum interbeat interval during inspiration and the maximum interbeat interval during expiration" (Hofmann et al., 2005; p. 466). This quantification of RSA is also called peak-valley method (Grossman, 1983; Grossman, Beek, & Wientjes, 1990). To make things even more complex, RSA has also been used to refer to HF in combination with unusual cut-off values (e.g., 0.15 to 0.50 Hz, see Elkins et al., 2009). Similar problems apply to the use of other parameters as well, for example, normalized units are expressed as HF nu (e.g., Udupa et al., 2011), HF n.u. (Pollatos, Füstös, & Critchley, 2012), HF norm (e.g., Budzynski, Budzynski, Maret, & Tang, 2008), or nHF (e.g., Peng, Koo, & Yu, 2009). It takes no wonder, then, that different authors use different calculation formulas: (a) HF nu = HF/(TP - VLF) × 100 (for example, used by Dishman, Jackson, & Nakamura, 2002; Nyklíček, Mommersteeg, Van Beugen, Ramakers, & Van Boxtel, 2013) or (b) HF nu = HF/TP × 100 (for example, used by Bär et al., 2008; Trachani et al., 2012). The Task Force (1996) recommends to use the first calculation method.

Finally, the coding of studies has been conducted by three different researchers. For economic reasons, rater agreement has been verified for the first seven studies. Subsequently, uncertainties and questions were collectively discussed until a consensus had been obtained. In addition, studies were sorted by the first letter of the first author, and each of the three raters reviewed a specific part of the alphabet. Hence, a random sample of studies has been rated.

2.4.8. Further Research and Conclusion

Due to the impressive increase of psychological research on HRV, the present review has revealed a great methodological and statistical heterogeneity, as well as frequent deviations from previously recommended standards (Task Force, 1996). Additionally, a large lack of information became apparent. Moreover, a comprehensive analysis of statistical software in this domain is still needed (e.g., see Sandercock, Shelton, Bromley, & Brodie, 2004). The same is true for the used measuring devices and the application of nonlinear analyses. Given this state of affairs, we provided some specific recommendations, which can be considered as a helpful orientation for future studies (see Figure 8).

In sum, future research in the field of psychological research on short-term HRV should further elaborate on the actualization and specification of suitable standards in the measurement, analysis, and interpretation of HRV. This also includes a standardized handling of respiration, the use of nonlinear methods, the definition of recording and analysis intervals, participant inclusion criteria, spectral analysis methods, posture during recording, instruction of the participants, technical specifications, and the parameter presentation and interpretation (especially LF and LF/HF). Such updated standards should include clear recommendations as well as requirements as to which methodological aspects and parameters must be reported. To meet these demands adequately, a collaboration in interdisciplinary teams is extremely important. A renewal of universal guidelines also requires an effective and binding communication process, including researchers, editors, and reviewers. As a next step, we may be able to generate specific norm values for different samples and populations.

Chapter III

3. Reliability of Short-Term Measurements of Heart Rate Variability

Findings from a Longitudinal Study

Uhlig, S.[1], Meylan, A.[1], & Rudolph, U.[1]

[1]*Chemnitz University of Technology, General Psychology and Biopsychology*

Abstract

The assessment of heart rate variability (HRV) is a widely-used approach to investigate the autonomic nervous system. However, test-retest reliability of HRV measurements is far from clear. The goal of the present study is to provide insights into relative and absolute reliability of the most common HRV parameters. In addition, our data allow for an analysis of posture effects. We analysed 103 healthy students (83 women, mean age 21.72 ± 3.31 years) over a period of twelve months by assessing five-minute HRV at five measurement sessions during supine, sitting, and standing. We evaluated relative reliability by intraclass correlation coefficients and absolute reliability by standard errors of measurement, smallest real differences, and 95% limits of random variation. We find no systematic mean differences between measurements. However, there are significant effects of participants' posture (with η_p^2 ranging from .180 to .895, all *p*s < .001). Intraclass correlation coefficients are quite low (supine: .49 to .64, sitting: .40 to .57, standing: .35 to .56). Absolute reliability indicators reveal a large amount of random variation between test and retest (within individuals), especially for frequency domain parameters. Influences of posture and temporal distance between measurements on test-retest reliability are small and largely unsystematic. We conclude that test-retest measurements of HRV are characterized by a large extent of random variation, thus exacerbating the detection of HRV changes over time.

Keywords: heart rate variability, stability, reliability, reproducibility, short-term, posture

3.1. Introduction

Two decades ago, the formulation of specific guidelines for measurement, interpretation, and use of heart rate variability (HRV) by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) represented one of the most important milestones in research on HRV. Since then, an increasing number of psychological studies in this area have been published, relating HRV to psychological concepts (see Chapter I). Moreover, the great interest in this non-invasive and economical method is also evident in other fields of scientific research (e.g., sport science, medicine, occupational science) and in clinical practice (Dong, 2016; Francesco et al., 2012; Makivić et al., 2013; Nunan et al., 2010; Pinna et al., 2007; Sammito et al., 2015; Sandercock, 2007).

An important reason for the increasing interest in HRV is its relationship to various aspects of psychological functioning. In general, periodic fluctuations of the heart rate, that is the variability of the interbeat intervals (IBI), are regarded as an index of the interaction between parasympathetic and sympathetic branches of the autonomic nervous system (Appelhans & Luecken, 2006; ChuDuc et al., 2013; Riganello et al., 2012; Shaffer et al., 2014; Stein & Kleiger, 1999; Task Force, 1996). Overall, there is consensus that high variability is associated with positive functioning, such as health and good adaptability to situational requirements (Appelhans & Luecken, 2006; Beauchaine, 2001; Quintana & Heathers, 2014; Shaffer et al., 2014). In contrast, low HRV has been regarded as a risk factor for negative outcomes, such as cardiovascular diseases, mental disorders, or mortality (Appelhans & Luecken, 2006; ChuDuc et al., 2013; Eller-Berndl, 2015; La Rovere et al., 2003; Nunan et al., 2010; Riganello et al., 2012; Stein & Kleiger, 1999; Thayer & Lane, 2007), as well as subclinical phenomena, such as stress (Berntson & Cacioppo, 2004; Jarczok et al., 2013; Schubert et al., 2009) or anxiety (Miu et al., 2009; Watkins et al., 1998).

Thus, the analysis of HRV is associated with a wide range of research topics and applications, many of them relevant for health behaviour or health-related decisions (for example, see De Bock, Jarczok, Hoffmann, & Buchhorn, 2013; Hoyer, 2009; Pumprla et al., 2002; Shaffer et al., 2014). Within clinical contexts, it is crucial to detect changes over time, and to distinguish such changes (e.g., due to medical interventions) from random variation (Sole, Hamrén, Milosavljevic, Nicholson, & Sullivan, 2007). Such a differentiation between random and real changes is particularly difficult if single persons or small samples without control group are investigated.

3.1.1. A Brief Introduction into Test-Retest Reliability

Before taking a closer look at previous studies on test-retest reliability of HRV measurements, some specific concepts of test-retest reliability analyses are worth mentioning. Atkinson and Neville (1998) define reliability in this context "as the consistency of measurements […] on a test; or *the absence of measurement error*" (p. 219). In this context, the terms "*repeatability*, *reproducibility*, *consistency*, *agreement*, *concordance* and *stability"* (Atkinson & Nevill, 1998, p. 219) have often been used synonymously; as well as *intra-subject reproducibility* (Pinna et al., 2007) and *test-retest reliability* (Sole et al., 2007). However, as Weir (2005) pointed out, strictly speaking, some of these terms do not represent identical concepts. To avoid inconsistencies, we distinguish between *relative* and *absolute reliability* (Baumgartner, 1989; Hallman et al., 2015; Maestri et al., 2009; Weir, 2005). While relative reliability provides information on the extent to which people retain their relative position within a sample during repeated measurements (Atkinson & Nevill, 1998; Baumgartner, 1989; Bruton, Conway, & Holgate, 2000; Sole et al., 2007; Weir, 2005), absolute reliability provides information about "the degree to which repeated measurements vary for individuals" (Atkinson & Nevill, 1998, p. 219), independent of an individual's rank within the sample. We will provide more detailed information on this topic in the methods section.

3.1.2. Test-Retest Reliability of HRV Measurements

First of all, it is astounding how little is thus far known about the test-retest reliability of short-term measurements of HRV (i.e., usually measurements of five minutes; Task Force, 1996). According to Sandercock and others (2005), HRV is mostly described as a reliable measure within the existing literature. However, in their review of studies analysing test-retest reliability (i.e., intra-subject reliability) of short-term HRV measurements, the authors conclude that this assumption oversimplifies the state of affairs, and that the available evidence is far from unambiguous. As summarized by Pinna and others (2007), there are numerous potential reasons for this heterogeneity, such as different or inconsistent experimental conditions, the studied sample (e.g., healthy subjects vs. clinical populations; Sandercock et al., 2005), small sample sizes, the length of the time interval between test and retest, analysis intervals deviating from the Task Force recommendations (1996), selective parameter reporting, and the use of unsuitable reliability indices (see also Sandercock et al., 2005).

Therefore, let us briefly summarize results of previous studies on test-retest reliability and temporal stability of short-term HRV measurements. As the review by Sandercock and others (2005) provides an almost exhaustive overview of studies published before 2004, we mainly focus on studies that have been carried out since then. These studies also differ with respect to important methodological characteristics, such as their use of reliability indices (e.g., relative vs. absolute reliability indices), the time interval between the measurement sessions (e.g., one day vs. several months), the number of measurements (e.g., one retest vs. multiple retests), treatment of respiration effects (e.g., paced vs. spontaneous breathing), subjects' activity during measurements (e.g., rest vs. physical activity), sample sizes and characteristics (e.g., children vs. seniors), subjects' posture during measurements (e.g., standing vs. sitting vs. supine), HRV parameters investigated (e.g., frequency vs. time domain parameters), or length of analysed electrocardiogram (ECG) recordings (e.g., two minutes vs. five minutes). Consequently, this heterogeneity impedes comparability between studies.

3.1.2.1. Relative Reliability

The majority of authors report satisfactory to excellent relative reliability results for most HRV parameters (for example, see Bertsch, Hagemann, Naumann, Schächinger, & Schulz, 2012; Cipryan & Litschmannova, 2013, 2014; Dietrich et al., 2010; Guijt, Sluiter, & Frings-Dresen, 2007; Hallman et al., 2015; Kobayashi, 2009; Koskinen et al., 2009; Kowalewski & Urban, 2004; Maestri et al., 2009; Pinna et al., 2007; Schroeder et al., 2004; Young & Leicht, 2011). This applies both to studies with very short intervals between test and retest (≤ one day; e.g., Cipryan & Litschmannova, 2013, 2014; Maestri et al., 2009; Pinna et al., 2007; Young & Leicht, 2011), as well as to studies with longer intervals between measurements (> one week; e.g., Dietrich et al., 2010; Kobayashi, 2009; Koskinen et al., 2009; Schroeder et al., 2004). Moreover, Hallman and others (2015) report that reliability is not influenced by the interval between repeated measurements (up to six months). In this vein, paced breathing tends to increase relative reliability (as compared to spontaneous breathing). However, these effects seem to be small and partly unsystematic (Bertsch et al., 2012; Kobayashi, 2009; Maestri et al., 2009; Pinna et al., 2007). In addition, the impact of subjects' posture (standing vs. supine; standing vs. sitting vs. supine, respectively) on relative reliability appears as small to non-existent, although there are noticeable differences in the magnitude of HRV parameters (Cipryan & Litschmannova, 2013, 2014; Dietrich et al., 2010; Kowalewski & Urban, 2004; Young & Leicht, 2011). Furthermore, some authors report higher reliability indices for time domain parameters as compared to frequency domain parameters (Mukherjee, Yadav, Yung, Zajdel, & Oken, 2011; Young & Leicht, 2011).

3.1.2.2. Absolute reliability

It is noteworthy that several very carefully conducted studies reveal a remarkable gap between relative and absolute reliability (above all Cipryan & Litschmannova, 2013, 2014; Maestri et al., 2009; Pinna et al., 2007). This becomes evident when estimating the extent of random variation between test and retest. Pinna and others (2007), while finding (cum grano salis) good relative reliability, report large day-to-day random variations in healthy subjects and larger intra-subject variability for frequency domain parameters. These patterns are observed for both paced and spontaneous breathing. Similar results within a clinical sample (post myocardial infarction patients) are reported by Maestri and colleagues (2009). In addition, there is a high degree of random variation within subjects, even for immediate repetitions of measurements (Cipryan & Litschmannova, 2013, 2014). Again, these results appear to be only partially dependent on the subjects' posture during ECG recording (standing vs. supine).

3.1.3. Aim of the Study

To summarize, the available evidence on test-retest reliability of HRV measurements is far from clear. Also note that existing studies differ with respect to important methodological characteristics, and relatively little is known concerning reliability of HRV measurements with long intervals between test and retest (> two months). To provide more detailed insights into the relative and absolute reliability of short-term HRV over longer time intervals, we designed a study with the following characteristics: (a) Multiple measurements per subject spreading over an interval of approximately one year, (b) a sufficiently large sample size, (c) an analysis of the influence of time intervals between measurements, (d) an analysis of the influence of different postures during measurements, and (e) strict conformity to established recommendations for HRV measurements and their reporting (Quintana et al., 2016; Task Force, 1996) as well as widely accepted standards for reliability analyses (e.g., see Atkinson & Nevill, 1998; Baumgartner, 1989; Bland & Altman, 1996a; Sandercock, 2007; Sandercock et al., 2005; Weir, 2005).

3.2. Methods and Materials

3.2.1. Participants

Participants were *N* = 172 students of the Chemnitz University of Technology (*n* = 129 women; age range between 18 and 39 years, with *M* = 22.20 and *SD* = 4.03). The first measurement (t1; *N* = 171) took place in November 2014, the second (t2; *N* = 159) in January 2015, the third (t3; *N* = 152) in April 2015, the fourth (t4; *N* = 142) in June 2015, and the fifth (t5; *N* = 131) in October 2015. Thus, the average time interval between t1 and t2 is two months, between t2 and t3 three months, between t3 and t4 two months, and between t4 and t5 four months. Time intervals vary as all measurements had to take place during the semester.

N = 120 subjects were present at all five measurements (*n* = 96 women, age range was 18-36 years, with *M* = 21.78 and *SD* = 3.59), resulting in a drop-out rate of 30.2 % over a time interval of twelve months. Within this sample, it was not possible to assess all ECG recordings for all kinds of postures. That is, one student needed a wheelchair, and two participants did not feel comfortable in a given position (hence, the recording had to be stopped). We also had to exclude recordings due to too many artefacts; consequently, there are *n* = 5, *n* = 6, and *n* = 7 missing measurements in the sitting, standing, and supine position, respectively, affecting a total of *n* = 12 cases. Finally, we had to exclude the data of one participant due to a cardiac disease, and four cases because of medications influencing the autonomic system. As a result, *N* = 103 subjects were included in the study (83 women, with an age range from 18 to 35 years, with *M* = 21.72 and *SD* = 3.31). All data and calculations reported here refer to this final sample.

In line with the Declaration of Helsinki (World Medical Association, 2013), the present study has been approved by the local ethics committee of the Chemnitz University of Technology. Participants were informed in detail about procedure and objectives of the study. Participation in the study was voluntary and could be cancelled at any time without giving reasons. Additionally, the subjects received contact information in case of problems or questions. All data were completely anonymized for further processing, by asking each participant to generate his/her specific individual code. Participants gave their written informed consent and received course credit. They were instructed by e-mail to refrain from smoking, caffeine, alcohol, heavy physical activity, and heavy meals two hours prior to the measurement (see Chapter II). Health status, current medication, substance consumption (alcohol, caffeine, nicotine), and physical activity were assessed by a standardized questionnaire. Table 8 summarizes the main sample characteristics.

Table 8

Sample Characteristics at First Measurement (t1)

Variable	Female (*n* = 83)	Male (*n* = 20)	Total (*N* = 103)
Age, *M* ± *SD* (years)	21.31 ± 3.06	23.40 ± 3.83	21.72 ± 3.31
Height, *M* ± *SD* (cm)	168.59 ± 6.08	180.05 ± 5.85	170.82 ± 7.54
Weight, *M* ± *SD* (kg)	61.90 ± 8.57	74.15 ± 8.76	64.28 ± 9.85
Body mass index, *M* ± *SD*	21.78 ± 2.75	22.93 ± 3.02	22.00 ± 2.83
Smoker/non-smoker/ex-smoker	9/68/6	3/15/2	12/83/8
< 5 cigarettes/day	5	1	6
5-10 cigarettes/day	4	2	6
Coffee consumption: yes/no	38/45	12/8	50/53
Alcohol consumption			
no	10	3	13
< once a week	5	-	5
once a week	55	12	67
up to three times/week	13	4	17
up to five times/week	-	1	1
Sport/no sport	64/19	16/4	80/23

3.2.2. Study Protocol and Study Design

The study conditions were kept as constant as possible for each measurement (t1-t5). During the weekend prior to their respective date, subjects received an e-mail reminder, summarizing important information about the study. Measurements were carried out in a quiet laboratory room at a comfortable temperature. Day times of measurements were between 8.00 am and 6.00 pm.

Upon arrival at the laboratory, participants were randomly assigned to one of six conditions, resulting in a 2 × 3 experimental design: (a) The first independent variable was the primary order condition: Half of the participants started the experiment by filling out questionnaires, such as psychological inventories; the other half started with the ECG recording. In average, it took about 30 minutes to answer the questionnaires. The same amount of time was needed for the ECG recording (see below). (b) The second independent variable was the order of postures within the ECG recording, with three order conditions (sitting, supine, standing vs. standing, sitting, supine vs. supine, standing, sitting). The resulting six conditions serve as controls of order effects. Regardless of the order conditions, each participant started the experiment by receiving an informed consent, a written instruction, and demographic questions. At the end of each measurement (except t5, the last measurement), participants were reminded of the next measurement occasion. Overall, each session lasted approximately one hour. Since all students were measured at all occasions in all three positions, this is a nested within-subjects design.

3.2.3. ECG Data Recording and Processing

All assessments were conducted by two experimenters, one female and one male. Hence, we ensured that participants were supervised and cabled by a same-sex experimenter. Note that a pilot study had revealed that male participants have higher heart rates given they are supervised by a female experimenter (as compared to a male experimenter).

We acquired ECG signals by a three-clamp-electrode ECG system (SUEmpathy100; SUESS Medizin-Technik, Aue, Germany) with disposable adhesive electrodes (Dahlhausen type 405, Ag/AgC1; 45 mm diameter), attached to the upper body of the participant. The ECG sampling rate was 512 Hz with 12-bit resolution. We used the SUEmpathy analysis software (version SUE1-4.36j Scientific) and calculated the relevant HRV parameters offline (see below).

Following the cabling procedure and signal verification, we asked the participants to move into the first predetermined position (either sitting, standing, or supine). They were instructed to adopt the subjectively most comfortable position and to relax while breathing spontaneously; respiration was not recorded. According to the guidelines of the Task Force (1996), we analysed a five-minute interval. To increase the likelihood of an artefact-free five-minute interval, we recorded eight minutes for each posture (= recording interval). After finishing the first (or second) position, participants were given two minutes to move slowly into the next position. During the entire measurement, the investigator paid attention to potentially artefact-causing behaviours (e.g., movements or respiratory irregularities). The corresponding markers were used for artefact clean-up after measurement.

Each participant's analysis interval represents a standardized cut-out of the recording interval, that is, five minutes between minute two and minute seven. We only deviated from this procedure when artefacts became apparent within this interval and when another artefact-free interval was available (e.g., between minute one and six). In accordance with Task Force requirements (1996), we visually checked the entire interbeat interval series for each subject, and manually edited the data if artefacts were observed (see also de Vries, 2013). Note that our software allows to manually edit these artefacts without altering the time reference within each recording.

We calculated the mean heart rate (HR) and the mean IBI as well as parameters referring to time and frequency domain analysis. We used the following time domain parameters, which are suitable for short-term analysis of HRV (these parameters are described in more detail within Chapter I as well as by Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; Eller-Berndl, 2015; Ikawa et al., 2001; Nunan et al., 2010; Shaffer et al., 2014; Stein & Kleiger, 1999; Task Force, 1996): The standard deviation of IBIs (SDNN; in ms), the square root of the mean squared differences of consecutive IBIs (rMSSD; in ms), the percentage of successive IBIs with a difference > 50 ms (pNN50; in %), and the coefficient of variation of IBIs (CV; in %).

We computed spectral analysis of recorded interbeat intervals by using the Trigonometric Regressive Spectral Analysis. The Trigonometric Regressive Spectral Analysis describes the original interbeat intervals (not interpolated) with the help of trigonometric regressive functions (for more information, see Rüdiger, Klinghammer, & Scheuch, 1999; Ziemssen, Reimann, Gasch, & Rüdiger, 2013). The following recommended frequency domain parameters were calculated and used for further analyses (for detailed information, see Allen et al., 2007; Appelhans & Luecken, 2006; Cygankiewicz & Zareba, 2013; Eller-Berndl, 2015; Pumprla et al., 2002; Shaffer et al., 2014; Task Force, 1996): The high frequency band with a range of 0.15 to 0.40 Hz (HF; in ms^2), the low frequency band (LF; 0.04 to 0.15 Hz; in ms^2), the total power (TP; ≤ 0.40 Hz; in ms^2), the ratio of LF and HF (LF/HF), and the normalized units (nu) of HF and LF using these equations: HF nu = HF/(TP - VLF)×100; LF nu = LF/(TP - VLF)×100 (Task Force, 1996). Although we computed the very low frequency (VLF; ≤ 0.04 Hz; in ms^2), this parameter will not be taken into account in our analyses, because this is not recommended for short-term measurements (Task Force, 1996).

3.2.4. Statistical Analyses

Before describing the performed analyses of the present study, we need to deepen the above-mentioned distinction between relative and absolute reliability. Specifically, we will consider the most common indices and their respective properties.

3.2.4.1. Relative Reliability

In the context of relative reliability analyses, correlation coefficients, such as *intraclass correlation coefficients* (*ICC*s), are typically calculated (Atkinson & Nevill, 1998; Baumgartner, 1989; Bruton et al., 2000; Pinna et al., 2007; Weir, 2005). *ICC*s can be computed directly from the output of the ANOVA and are to be preferred to Pearson`s correlation coefficients for several reasons (see also Bland & Altman, 1996b; Bruton et al., 2000; Caruso, Brown, & Tufano, 2012). Nevertheless, note that different models for calculating *ICC*s exist, sometimes leading to divergent results (Atkinson & Nevill, 1998; Bruton et al., 2000; McGraw & Wong, 1996; Shrout & Fleiss, 1979; Weir, 2005). Choosing the correct method can be a challenging task and may provoke disagreements. Second, *ICC*s are principally based on between- and within-subject variance, total variance, true variance, and error variance, respectively (Bertsch et al., 2012; Bland & Altman, 1996b; Dietrich et al., 2010; Shrout & Fleiss, 1979). As a consequence, with increasing heterogeneity of the sample, *ICC*s necessarily increase (i.e., these get closer to 1.0; see also Pinna et al., 2007; Weir, 2005). Hence, *ICC*s may reach high levels even when within-subjects variation is in fact large. Accordingly, different conventions for the interpretation of *ICC* values have been proposed (Atkinson & Nevill, 1998; Fleiss, 1986; Pinna et al., 2007; Shrout, 1998; Shrout & Fleiss, 1979; Weir, 2005). In the present study, we will refrain from classifying *ICC*s into simple categories such as *poor*, *fair*, *good*, or *excellent*, as this oversimplifies the state of affairs.

3.2.4.2. Absolute Reliability

Indicators for absolute reliability are, for example, the *standard error of measurement* (*SEM*), the *smallest real difference* (*SRD*), the *coefficient of variation* (*CV%*), or *Bland and Altman´s 95% limits of agreement* (Atkinson & Nevill, 1998; Bland & Altman, 1996a, 1999, 2010; Bruton et al., 2000; Pinna et al., 2007; Sole et al., 2007; Weir, 2005). *SEM* and *SRD* can be expressed as units of the investigated variable. The *SEM*, one of the most important indices of absolute reliability (Atkinson

& Nevill, 1998; Dietrich et al., 2010; Pinna et al., 2007; Weir, 2005), is used to define those limits for the smallest variation which can be considered as a meaningful change for groups of subjects (Flansbjer, Holmbäck, Downham, Patten, & Lexell, 2005; Sole et al., 2007). Thus, the *SEM* provides information about the random variability of individual values for repeated measurements (Hopkins, 2000) and "covers about 68 % of the variability" (Atkinson & Nevill, 1998, p. 229). Consequently, there is an inverse relationship between test-retest reliability and the *SEM*.

When determining the smallest meaningful (or real) difference for individuals, the *SRD* should be calculated as covering 95 % of the variability (Beckerman et al., 2001; Flansbjer et al., 2005; Sole et al., 2007; Weir, 2005). The *SRD* is also called *minimum difference* (Weir, 2005) or *repeatability coefficient* (Bland & Altman, 1999, 2010; Bruton et al., 2000; Pinna et al., 2007). Moreover, the *SRD* can be used to specify the *95% limits of random variation* (Atkinson & Nevill, 1998; Bland & Altman, 1999). These limits are described as follows:

> […] The range of values within which 95% of the differences between two measurements […] are expected to lie due to pure random variation. For log-transformed variables, these limits […] [have to be] back-transformed (antilogarithm), giving the range of values within which 95% of the ratios between […] two measurements […] are expected to lie due to pure random variation. (Pinna et al., 2007, p. 133)

Sometimes, data are characterized by heteroscedasticity, that is, measurement errors are related to the magnitude of the measured variable, with higher HRV scores producing higher measurement errors/standard deviations or vice versa (Hopkins, 2000). In such cases, the *CV%* is the index of choice (Atkinson & Nevill, 1998). Thus, a *CV%* of 10 % means that approximately 68 % of all test-retest differences are located within a 10% range around the mean of the data (given a normal distribution, see Atkinson & Nevill, 1998; Dietrich et al., 2010).

3.2.4.3. Performed Analyses

To take all these considerations into account, we analyse the test-retest reliability of HRV measurements in four steps: First, we provide descriptive statistics of the raw data. Unrealistic or illogical values are sought, supplemented, and/ or corrected by re-examining the dataset in question. Nevertheless, known distribution problems of HRV parameters may become evident (for example, see Dietrich et al., 2010; Hallman et al., 2015; Pinna et al., 2007). Since tests for normal distribution (e.g., Shapiro-Wilk test) reach significance more easily in large samples, we additionally use Q-Q plots to evaluate the distribution (Field, 2013). Thus, all skewed variables are transformed by using the natural logarithm (ln; for example, see Bland & Altman, 1996c, 1999; Dietrich et al., 2010; Field, 2013; Pinna et al., 2007). Subsequently, we will check the data for heteroscedasticity by plotting the individual standard deviations and their means as well as by calculating Kendall's tau (τ; as proposed by Bland & Altman, 1996a).

In a second step, we calculate a 3 × 5 (Postures × Measurements) repeated-measures analysis of variance (ANOVA) for each parameter. If the assumption of sphericity is violated (Mauchly’s test of sphericity), we apply Greenhouse-Geisser corrections. Furthermore, we calculate separate one-way repeated-measures ANOVAs for each parameter and each posture to check for systematic differences between measurements (Atkinson & Nevill, 1998; Weir, 2005). Effect sizes are reported as partial eta squared (η_p^2). According to Cohen (1988), effect sizes of $\eta_p^2 > .009$ can be considered as small, $\eta_p^2 \geq .059$ as medium, and $\eta_p^2 \geq .138$ as large. Additionally, post hoc tests are carried out (Bonferroni).

Step three includes analyses of relative reliability by calculating the $ICC_{3,1}$ (Shrout & Fleiss, 1979) and the associated 95 % confidence interval for each HR(V) parameter for each position: $ICC_{3,1}$ = (BMS - EMS)/(BMS + (m - 1)EMS), with BMS being the between-subjects mean square, EMS is the residual mean square (respective error mean square) within the within-subjects variance, and m the number of measurements per subject. Note that this equation is mathematically identical to the *ICC* (C,1) of the nomenclature proposed by McGraw and Wong (Koo & Li, 2016; McGraw & Wong, 1996; Weir, 2005). We use a two-way mixed effects single measures model (consistency), as this has been used in comparable studies (e.g., Guijt et al., 2007; Santos, Pavão, Avila, Salvini, & Rocha, 2013; Sole et al., 2007). Moreover, according to detailed explanations by Weir (2005), a two-way model is appropriate, as each subject has been measured at all occasions. Model 3 instead of model 2 seems appropriate, because we assumed only a random and no systematic error (i.e., systematic differences between measurement sessions). Moreover, we use a single measure score, because we obtained single measures for each subject at each measurement session. Within our data, *ICCs* are almost identical, regardless of different calculation methods (i.e., models). This supports the assumption that effects of systematic error are very small (Weir, 2005). First, we will calculate the *ICC*s by including all five measurement sessions. Additionally, we will determine the *ICC*s for all paired combinations with t1 to investigate whether relative reliability changes systematically when temporal distance to t1 increases.

Step four consists of an investigation of absolute reliability. We will calculate the *SEM* for each parameter and each posture by using the error mean square (as obtained from the ANOVA output). This calculation is independent of the *ICC,* and thus independent of between-subjects variability (Bland & Altman, 1996a; Weir, 2005): *SEM* = √EMS. The *SRD* will be computed by *SRD* = *SEM* × 1.96 × √2 (Beckerman et al., 2001; Flansbjer et al., 2005; Sole et al., 2007; Weir, 2005). Finally, we will use the *SRD* to calculate the 95% limits of random variation. As we need to apply a log-transformation for most of the parameters, we calculate the antilog of the limits (i.e., the antilog of the *SRD*). This procedure is explained in more detail elsewhere (Atkinson & Nevill, 1998; Bland & Altman, 1996c, 1999, 2010; Pinna et al., 2007). As a result, the 95% limits of random variation are given, as a difference between two measurements for non-transformed parameters (± *SRD*), and as a ratio between two measurements for initially log-transformed parameters (÷/×

e^{SRD}) leading to asymmetrical intervals (Pinna et al., 2007). Again, we perform these calculations for all five measurements as well as for all paired combinations with t1.

All analyses were performed with IBM SPSS Statistics 24 or MS Excel 2016. The underlying dataset and additional material (e.g., the demographic questions) are available online. All data can be retrieved from a public repository (Open Science Framework; http://doi.org/10.17605/OSF.IO/FYQV7).

3.3. Results

3.3.1. Descriptive Statistics

Arithmetic means and standard deviations are given in Table 9. Note that all parameters except mean HR and mean IBI are characterized by skewed distributions, as indicated by Shapiro-Wilk-tests ($p < .05$) and upon inspection of the Q-Q plots. Therefore, these HRV parameters were log-transformed (ln), leading to normal distributions for SDNN, rMSSD, CV, HF, LF, LF/HF, and TP (all postures, all measurements; see Table 10). For HF nu, LF nu, and pNN50, log-transformation did not result in normal distributions (especially for sitting and standing measurements). As these serious distribution problems as well as heteroscedasticity are evident for all measurement sessions (independent of different data transformation attempts), we decided to exclude HF nu, LF nu, and pNN50 from further calculations.

Table 9

Raw Values of HR(V) Parameters for Three Postures at all Measurements (N = 103)

Parameter	Posture	M_{t1} (*SD*)	M_{t2} (*SD*)	M_{t3} (*SD*)	M_{t4} (*SD*)	M_{t5} (*SD*)	$M_{t1\text{-}t5}$ (*SD*)
HR (bpm)	supine	69.07 (10.06)	67.17 (8.44)	68.05 (10.06)	67.24 (7.83)	67.25 (8.91)	67.76 (6.86)
	sitting	76.84 (9.99)	75.44 (8.53)	75.67 (10.91)	76.77 (9.09)	75.70 (10.41)	76.09 (7.03)
	standing	92.72 (12.56)	92.21 (11.47)	91.60 (13.49)	94.07 (11.64)	91.16 (12.53)	92.35 (8.62)
IBI (ms)	supine	886.33 (124.98)	907.68 (116.16)	899.50 (125.72)	903.86 (107.42)	906.93 (115.89)	900.86 (91.77)
	sitting	794.03 (101.79)	805.58 (92.81)	808.32 (110.66)	792.35 (91.60)	806.58 (105.21)	801.37 (72.92)
	standing	656.87 (84.83)	660.62 (81.53)	668.25 (93.04)	651.90 (84.87)	668.53 (86.63)	661.23 (59.60)
SDNN (ms)	supine	63.90 (30.12)	67.61 (33.32)	65.52 (32.39)	65.85 (34.10)	68.15 (32.02)	66.21 (26.90)
	sitting	53.70 (23.96)	53.71 (20.37)	55.75 (20.76)	53.28 (19.93)	59.01 (31.35)	55.09 (17.13)
	standing	39.23 (15.97)	39.50 (14.25)	40.73 (16.08)	38.63 (14.91)	43.20 (18.67)	40.26 (12.42)
rMSSD (ms)	supine	64.18 (40.09)	69.15 (47.72)	65.93 (44.67)	69.06 (48.43)	69.13 (44.64)	67.49 (38.79)
	sitting	41.45 (23.79)	41.79 (23.55)	43.68 (26.65)	40.83 (25.70)	46.00 (40.21)	42.75 (19.39)
	standing	20.27 (11.76)	19.57 (9.62)	20.78 (12.79)	18.50 (11.45)	21.19 (12.00)	20.06 (8.87)
pNN50 (%)	supine	36.12 (24.34)	36.31 (24.17)	35.39 (25.65)	36.27 (25.46)	37.32 (24.24)	36.28 (20.82)
	sitting	20.49 (18.12)	21.16 (19.54)	22.82 (20.22)	19.06 (17.89)	22.84 (18.91)	21.27 (14.98)
	standing	4.67 (7.42)	3.75 (5.59)	5.01 (8.68)	3.38 (5.85)	4.91 (7.62)	4.35 (5.17)
CV (%)	supine	7.32 (3.34)	7.31 (3.09)	7.19 (2.95)	7.13 (3.20)	7.42 (3.10)	7.27 (2.61)
	sitting	6.74 (2.59)	6.62 (2.24)	6.84 (2.15)	6.66 (2.15)	7.14 (3.12)	6.80 (1.85)
	standing	5.85 (1.87)	5.91 (1.93)	6.04 (2.03)	5.89 (1.91)	6.28 (2.27)	5.99 (1.59)
HF (ms^2)	supine	2089 (2748)	2599 (3668)	2252 (2807)	2490 (3486)	2369 (2950)	2360 (2626)
	sitting	913.44 (1100)	1057 (1323)	1128 (1380)	952.36 (1526)	1212 (2326)	1052 (1044)
	standing	272.81 (288.59)	241.81 (238.66)	292.11 (428.49)	217.63 (334.87)	251.25 (277.26)	255.12 (237.63)

Table 9 (continued)

Raw Values of HR(V) Parameters for Three Postures at all Measurements (N = 103)

Parameter	Posture	M_{t1} (*SD*)	M_{t2} (*SD*)	M_{t3} (*SD*)	M_{t4} (*SD*)	M_{t5} (*SD*)	$M_{t1\text{-}t5}$ (*SD*)
HF nu (%)	supine	52.84 (21.59)	55.16 (17.56)	50.65 (19.68)	54.17 (18.88)	53.25 (20.46)	53.22 (16.23)
	sitting	38.67 (18.20)	41.04 (19.37)	39.42 (20.19)	37.26 (18.29)	36.91 (19.23)	38.66 (15.52)
	standing	23.20 (16.31)	22.24 (14.04)	21.01 (14.38)	18.02 (12.49)	19.02 (12.85)	20.70 (11.30)
LF (ms^2)	supine	1758 (2808)	1801 (2228)	1840 (2179)	1539 (1759)	1803 (2698)	1748 (1799)
	sitting	1672 (3018)	1267 (1174)	1336 (1213)	1246 (1216)	1896 (2843)	1483 (1398)
	standing	952.88 (1426)	888.91 (931.09)	964.11 (1003)	886.40 (799.59)	1223 (1629)	983.14 (1003)
LF nu (%)	supine	47.16 (21.59)	44.84 (17.56)	49.35 (19.68)	45.83 (18.88)	46.75 (20.46)	46.79 (16.23)
	sitting	61.33 (18.20)	58.96 (19.37)	60.58 (20.19)	62.74 (18.29)	63.09 (19.23)	61.34 (15.52)
	standing	76.80 (16.31)	77.76 (14.04)	78.99 (14.38)	81.98 (12.49)	80.98 (12.85)	79.30 (11.30)
LF/HF	supine	1.70 (2.72)	1.20 (1.49)	1.79 (3.57)	1.27 (1.47)	1.60 (2.54)	1.51 (1.77)
	sitting	2.65 (3.28)	2.49 (2.94)	2.56 (2.54)	2.79 (2.72)	2.96 (3.20)	2.69 (2.27)
	standing	5.89 (4.83)	6.16 (7.44)	6.73 (6.13)	7.90 (7.23)	7.17 (6.29)	6.77 (4.90)
TP (ms^2)	supine	3880 (4587)	4434 (5427)	4125 (4404)	4058 (4971)	4206 (4649)	4141 (4001)
	sitting	2612 (3663)	2344 (2133)	2485 (2191)	2217 (2512)	3138 (4546)	2559 (2170)
	standing	1240 (1637)	1143 (1074)	1271 (1236)	1117 (1041)	1492 (1810)	1253 (1155)

Notes. CV = coefficient of variation of IBIs; HF = high frequency power; HF nu = normalized units of HF; HR = (mean) heart rate; HRV = heart rate variability; IBI = (mean) interbeat interval; LF = low frequency power; LF nu = normalized units of LF; LF/HF = ratio of LF and HF; pNN50 = percentage of successive IBIs with a difference > 50 ms; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power; t1 = first measurement; t2 = second measurement; t3 = third measurement; t4 = fourth measurement; t5 = fifth measurement; t1-t5 = all measurements.

Table 10

Descriptive Data for Skewed HRV Parameters for Three Postures at all Measurement Occasions after log-Transformation (N = 103)

Parameter	Posture	M_{t1} (*SD*)	M_{t2} (*SD*)	M_{t3} (*SD*)	M_{t4} (*SD*)	M_{t5} (*SD*)	M_{t1-t5} (*SD*)
ln HR	supine	4.23 (0.14)	4.20 (0.13)	4.21 (0.14)	4.20 (0.12)	4.20 (0.13)	4.21 (0.10)
(ln bpm)	sitting	4.33 (0.13)	4.32 (0.11)	4.32 (0.14)	4.33 (0.12)	4.32 (0.13)	4.32 (0.09)
	standing	4.52 (0.13)	4.52 (0.12)	4.51 (0.14)	4.54 (0.12)	4.50 (0.13)	4.52 (0.09)
ln SDNN	supine	4.05 (0.46)	4.11 (0.45)	4.06 (0.52)	4.07 (0.49)	4.12 (0.46)	4.08 (0.38)
(ln ms)	sitting	3.90 (0.40)	3.91 (0.39)	3.95 (0.39)	3.91 (0.36)	3.97 (0.46)	3.93 (0.30)
	standing	3.60 (0.37)	3.62 (0.35)	3.63 (0.41)	3.58 (0.38)	3.68 (0.42)	3.62 (0.28)
ln rMSSD	supine	3.97 (0.65)	4.04 (0.62)	3.97 (0.69)	4.01 (0.68)	4.04 (0.64)	4.01 (0.55)
(ln ms)	sitting	3.59 (0.53)	3.59 (0.54)	3.61 (0.60)	3.55 (0.58)	3.62 (0.62)	3.59 (0.44)
	standing	2.86 (0.56)	2.85 (0.51)	2.85 (0.65)	2.76 (0.58)	2.90 (0.57)	2.84 (0.44)
ln CV	supine	1.90 (0.41)	1.91 (0.39)	1.89 (0.40)	1.88 (0.42)	1.92 (0.40)	1.90 (0.33)
(ln %)	sitting	1.84 (0.35)	1.83 (0.35)	1.87 (0.32)	1.85 (0.30)	1.89 (0.37)	1.86 (0.26)
	standing	1.72 (0.30)	1.73 (0.30)	1.74 (0.33)	1.72 (0.32)	1.78 (0.33)	1.74 (0.24)
ln HF	supine	7.00 (1.24)	7.18 (1.17)	6.99 (1.33)	7.05 (1.31)	7.10 (1.22)	7.06 (1.06)
(ln ms^2)	sitting	6.30 (1.08)	6.35 (1.16)	6.36 (1.24)	6.21 (1.16)	6.37 (1.23)	6.32 (0.94)
	standing	5.05 (1.06)	5.00 (1.10)	4.92 (1.39)	4.67 (1.26)	4.98 (1.16)	4.92 (0.98)
ln LF	supine	6.90 (0.98)	6.96 (1.01)	6.98 (1.05)	6.86 (0.97)	6.98 (0.95)	6.94 (0.77)
(ln ms^2)	sitting	6.88 (0.94)	6.80 (0.85)	6.88 (0.81)	6.82 (0.77)	7.02 (0.98)	6.88 (0.68)
	standing	6.43 (0.88)	6.44 (0.81)	6.45 (0.98)	6.40 (0.95)	6.62 (0.96)	6.47 (0.72)
ln LF/HF	supine	-0.11 (1.04)	-0.20 (0.81)	-0.01 (0.96)	-0.17 (0.87)	-0.12 (0.99)	-0.12 (0.77)
	sitting	0.54 (0.89)	0.44 (0.95)	0.50 (0.98)	0.62 (0.92)	0.65 (0.92)	0.55 (0.75)
	standing	1.45 (0.83)	1.37 (1.00)	1.53 (0.90)	1.65 (1.03)	1.65 (0.84)	1.53 (0.70)
ln TP	supine	7.77 (1.00)	7.85 (1.03)	7.79 (1.10)	7.74 (1.08)	7.86 (1.00)	7.80 (0.86)
(ln ms^2)	sitting	7.42 (0.89)	7.40 (0.89)	7.46 (0.89)	7.35 (0.84)	7.55 (0.97)	7.44 (0.71)
	standing	6.75 (0.82)	6.72 (0.80)	6.72 (1.01)	6.63 (0.95)	6.86 (0.95)	6.74 (0.72)

Notes. CV = coefficient of variation of IBIs; HF = high frequency power; HR = (mean) heart rate; HRV = heart rate variability; IBI = interbeat interval; LF = low frequency power; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power t1 = first measurement; t2 = second measurement; t3 = third measurement; t4 = fourth measurement; t5 = fifth measurement; t1-t5 = all measurements.

Visual inspection for heteroscedasticity after log-transformation reveals no considerable relationship between individual standard deviations and means, suggesting homoscedasticity. By and large, statistical checks based on Kendall's τ support this conclusion, as only large correlations are considered problematic (supine: $\tau \leq .189$, $p \geq .005$; sitting: $\tau \leq .092$, $p \geq .167$; standing: $\tau \leq .246$, $p \geq .001$; all correlations are absolute values). As HR shows small heteroscedastic tendencies, we also log-transformed HR (see Table 10), leading to homoscedasticity. Exemplary scatterplots can be seen in Figure 9.

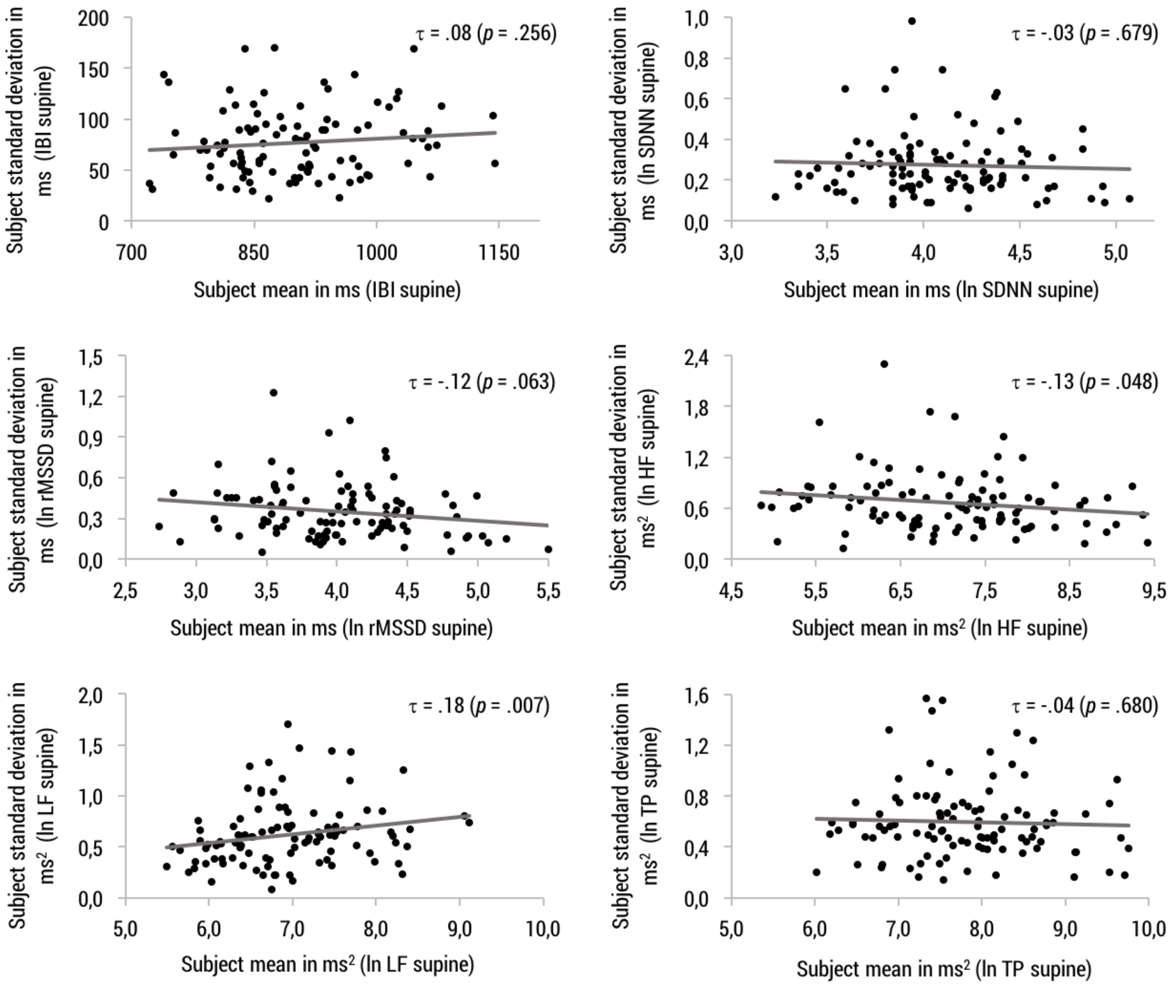


Figure 9. Individual subjects' standard deviations plotted against their arithmetic means. Relationships suggesting homoscedasticity (Bland & Altman, 1996a). Homoscedasticity is also present for the other postures and for ln HR, ln CV, and ln LF/HF. CV = coefficient of variation of IBIs; HF = high frequency; HR = heart rate; HRV = heart rate variability; IBI = interbeat interval; ln = natural logarithm; LF = low frequency; LF/HF = ratio of LF and HF; rMSSD = square root of mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power.

3.3.2. Comparing Postures, Measurement Sessions, and their Interaction

Two-way repeated-measures ANOVAs reveal large significant main effects of posture for all HR(V) parameters ranging from $\eta_p^2 = .180$ to $\eta_p^2 = .895$ (all *p*s < .001). As we can see from Tables 9 and 10, IBI, ln SDNN, ln rMSSD, ln CV, ln HF, ln LF, and ln TP consistently show highest means in the supine condition, followed by measurements with sitting and standing subjects. This order is reversed for ln HR and ln LF/HF ($M_{supine} < M_{sitting} < M_{standing}$). With only two exceptions (ln CV: $M_{supine} = 1.90$, $SE = 0.03$, $M_{sitting} = 1.86$, $SE = 0.03$, $p = .157$; ln LF: $M_{supine} = 6.94$, $SE = 0.08$, $M_{sitting} = 6.88$, $SE = 0.07$, $p = .778$), all post hoc tests for posture are significant (Bonferroni; $p < .001$).

In contrast, main effects for measurement session (time) are small and non-significant, suggesting that there are no systematic trends ($.009 \leq \eta_p^2 \leq .019$, $.093 \leq p \leq .444$). This general pattern is supported by non-significant post hoc tests for almost all parameters ($p \geq .166$). The only exception is ln LF/HF, $F(3.63, 370.22) = 3.01$, $p = .022$, $\eta_p^2 = .029$; here, the difference between t2 and t5 is significant ($M_{t2} = .54$, $SE = 0.07$, $M_{t5} = .73$, $SE = 0.08$, $p = .023$). Separate one-way repeated-measures ANOVAs for each parameter and each posture reveal analogous results, $F(4, 408) \leq 2.09$, $p \geq .081$, $\eta_p^2 \leq .020$, supporting the assumption that there are no systematic differences between measurement sessions. Exceptions are ln HF, standing: $F(3.66, 372.96) = 3.59$, $p = .009$, $\eta_p^2 = .034$, and ln LF/HF, standing: $F(3.48, 354.92) = 3.56$, $p = .010$, $\eta_p^2 = .034$.

Moreover, there are small interaction effects (Posture × Time) for ln HR, $F(6.24, 636.40) = 2.27$, $p = .033$, $\eta_p^2 = .022$, and ln HF, $F(6.96, 710.10) = 2.05$, $p = .047$, $\eta_p^2 = .020$. All other interaction effects are not significant. For an overview of all two-way repeated-measures ANOVAs (including effect sizes), see Table 11.

Table 11

Two-Way Repeated-Measures ANOVAs for HRV Indices with Posture and Measurement Session as Independent Variables (N = 103)

	Posture			Measurement session (time)			Posture × time		
Parameter	*F*	*df* (2, 204)	η_p^2	*F*	*df* (4, 408)	η_p^2	*F*	*df* (8, 816)	η_p^2
IBI	747.04***	1.49, 151.83	.880	0.97	4, 408	.009	1.42	5.86, 597.16	.014
ln HR	870.08***	1.56, 159.21	.895	1.00	4, 408	.010	2.27*	6.24, 636.40	.022
ln SDNN	139.43***	1.54, 156.92	.578	1.57	4, 408	.015	0.65	6.86, 699.51	.006
ln rMSSD	355.37***	1.47, 149.54	.777	0.92	3.53, 360.01	.009	1.14	6.59, 671.63	.011
ln CV	22.43***	1.59, 162.49	.180	1.28	4, 408	.012	0.45	7.06, 719.83	.004
ln HF	299.44***	1.45, 148.07	.746	1.77	4, 408	.017	2.05*	6.96, 710.10	.020
ln LF	36.82***	1.68, 170.97	.265	2.00	4, 408	.019	0.67	7.03, 717.46	.007
ln LF/HF	315.37***	1.55, 157.58	.756	3.01*	3.63, 370.22	.029	1.96	6.86, 699.81	.019
ln TP	124.48***	1.52, 155.04	.550	1.81	4, 408	.017	0.47	6.90, 703.39	.005

Notes. As indicated by the degrees of freedom (*df*), assumption of sphericity is violated several times (Mauchly's test of sphericity; $p < .05$). In these cases, we applied the Greenhouse-Geisser correction. Effect sizes of $\eta_p^2 > .009$ can be considered as small, $\eta_p^2 \geq .059$ as medium, and $\eta_p^2 \geq .138$ as large (J. Cohen, 1988). ANOVA = analysis of variance; CV = coefficient of variation of IBIs; HF = high frequency power; HR = (mean) heart rate; HRV = heart rate variability; IBI = (mean) interbeat interval; LF = low frequency power; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power.

* = $p < .05$, *** = $p < .001$, all other values are non-significant.

3.3.3. Test-Retest Reliability Analyses

3.3.3.1. Relative Reliability

First, we present results referring to calculations across all measurement sessions. As illustrated in Table 12, *ICC*s for measurements in supine position range from .49 (ln HR) to .64 (ln HF). An *ICC* of .64 suggests that 64 % of the observed variance of ln HF is attributable to variability within the true value, while 36 % of the variance (1 – *ICC*) should be traced back to random error (Pinna et al., 2007; Weir, 2005). Of course, this rule of interpretation can also be applied to all other values. For sitting measurements, *ICC*s tend to be smaller, with a range from .40 (ln HR) to .57 (ln LF/HF). Furthermore, *ICC*s for standing measurements vary between .35 (IBI) and .56 (ln HF), and are thus smaller as compared to the other postures (exceptions are ln HF and ln LF). In conclusion, highest *ICC*s occur for ln HF, ln rMMSD, and ln TP (supine), while lowest values arise for IBI and ln HR (standing and sitting). Interestingly, *ICC*s remain nearly identical when using a one-way random model (resulting in a maximum difference of .01) or a two-way random model (with a maximum difference that is identical to the second decimal). This suggests that the within-subjects variance is almost identical to the error variance (the systematic error is very small, respectively).

Variations in *ICC*s as a function of the temporal distance to t1 appear to be unsystematic (see also Table 12). That is, *ICC*s do not decrease as the time interval between measurements increases. For example, for most parameters and postures, *ICC*s between t1 and t4 (supine: .35 to .55; sitting: .18 to .50; standing: .21 to .66) are smaller than between t1 and t5 (supine: .54 to .64; sitting: .51 to .63; standing: .43 to .59). A comparison of the *ICC*s calculated from the shortest time interval (t1 and t2) with the *ICC*s calculated from the maximum time interval (t1 and t5) yields heterogeneous results. While larger *ICCs* are found for IBI, ln HR, and ln LF for the maximum time interval, there is no clear trend for the other parameters.

Table 12

Intraclass Correlation Coefficients ($ICC_{3,1}$; Shrout & Fleiss, 1979) and Associated 95% Confidence Intervals (95% CI) across all Measurement Sessions and for the Paired Combinations with t1

		All sessions	t1 × t2	t1 × t3	t1 × t4	t1 × t5
Parameter	Posture	*ICC* [95% CI]	*ICC* [95% CI]	*ICC* [95% CI]	*ICC* [95% CI]	*ICC* [95% CI]
IBI	supine	.50 [.41, .60]	.52 [.37, .65]	.55 [.40, .67]	.36 [.18, .51]	.62 [.49, .73]
	sitting	.41 [.31, .51]	.36 [.18, .52]	.32 [.14, .48]	.18 [.00, .36]	.63 [.50, .73]
	standing	.35 [.26, .45]	.35 [.17, .51]	.33 [.15, .49]	.21 [.02, .39]	.43 [.26, .58]
ln HR	supine	.49 [.40, .58]	.51 [.36, .64]	.52 [.36, .65]	.35 [.17, .51]	.63 [.49, .73]
	sitting	.40 [.31, .50]	.38 [.20, .53]	.34 [.16, .50]	.18 [.00, .36]	.58 [.44, .70]
	standing	.37 [.28, .47]	.36 [.18, .52]	.34 [.16, .50]	.25 [.06, .42]	.45 [.28, .59]
ln SDNN	supine	.56 [.47, .64]	.62 [.48, .73]	.53 [.37, .65]	.54 [.38, .66]	.60 [.46, .71]
	sitting	.46 [.37, .56]	.37 [.19, .52]	.37 [.19, .52]	.39 [.22, .55]	.56 [.41, .68]
	standing	.43 [.34, .53]	.43 [.26, .58]	.45 [.29, .60]	.37 [.19, .53]	.44 [.27, .58]
ln rMSSD	supine	.62 [.54, .70]	.68 [.56, .77]	.64 [.52, .74]	.49 [.33, .63]	.64 [.51, .74]
	sitting	.50 [.41, .59]	.49 [.32, .62]	.47 [.31, .61]	.32 [.14, .49]	.55 [.39, .67]
	standing	.47 [.38, .57]	.47 [.31, .61]	.54 [.39, .66]	.44 [.28, .59]	.46 [.29, .60]
ln CV	supine	.59 [.50, .67]	.63 [.50, .73]	.61 [.47, .72]	.55 [.40, .67]	.61 [.48, .72]
	sitting	.49 [.40, .58]	.44 [.27, .58]	.43 [.26, .58]	.50 [.34, .63]	.51 [.35, .64]
	standing	.47 [.38, .57]	.56 [.41, .68]	.48 [.31, .61]	.44 [.27, .58]	.45 [.29, .59]
ln HF	supine	.64 [.56, .72]	.70 [.58, .78]	.65 [.52, .75]	.54 [.39, .67]	.64 [.51, .74]
	sitting	.55 [.47, .64]	.52 [.37, .65]	.56 [.41, .68]	.40 [.23, .55]	.55 [.40, .68]
	standing	.56 [.47, .64]	.56 [.41, .68]	.61 [.47, .71]	.66 [.53, .75]	.46 [.29, .60]
ln LF	supine	.51 [.42, .60]	.51 [.35, .64]	.42 [.25, .57]	.50 [.33, .63]	.54 [.39, .66]
	sitting	.51 [.42, .60]	.41 [.24, .56]	.47 [.29, .60]	.44 [.27, .58]	.51 [.35, .64]
	standing	.52 [.43, .61]	.49 [.33, .62]	.56 [.41, .68]	.46 [.30, .60]	.53 [.37, .65]
ln LF/HF	supine	.58 [.50, .67]	.55 [.39, .67]	.61 [.48, .72]	.49 [.33, .62]	.64 [.50, .74]
	sitting	.57 [.48, .66]	.59 [.45, .71]	.54 [.39, .67]	.45 [.29, .59]	.58 [.43, .69]
	standing	.48 [.39, .58]	.52 [.37, .65]	.54 [.39, .66]	.42 [.24, .56]	.59 [.45, .70]
ln TP	supine	.60 [.51, .68]	.65 [.52, .75]	.57 [.43, .69]	.53 [.38, .66]	.60 [.46, .71]
	sitting	.53 [.44, .62]	.45 [.28, .59]	.48 [.32, .62]	.42 [.25, .57]	.54 [.39, .67]
	standing	.52 [.43, .61]	.52 [.36, .65]	.60 [.46, .71]	.54 [.39, .67]	.51 [.35, .64]

Notes. All *F*-tests are significant at $p < .05$. CV = coefficient of variation of IBIs; HF = high frequency; HR = heart rate; IBI = interbeat interval; LF = low frequency; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power; t1 = first measurement; t2 = second measurement; t3 = third measurement; t4 = fourth measurement; t5 = fifth measurement.

3.3.3.2. Absolute Reliability

Again, we will start with the calculations that have been carried out across all five measurements. Accordingly, the computed indices represent "average" measurement errors. Indicators of absolute reliability are summarized in Table 13. As all parameters except IBI were log-transformed, a simple interpretation of these values is only possible for IBI: A meaningful change for groups of subjects (= *SEM*) is given when the IBI between two measurements changes by at least 83.34 ms (supine), 77.61 ms (sitting), or 69.72 ms (standing). A 95% confidence suggesting that a meaningful change has taken place within an individual (= *SRD* or 95% limits of random variation) requires a difference of at least 231.02 ms (supine), 215.11 ms (sitting), and 193.27 ms (standing). *SEM* and *SRD* for all other parameters are specified in log units, which makes the interpretation more difficult.

For all the remaining parameters, see Table 14 (here, the indices were transformed back). As a result of the antilogarithmic transformation, the 95% limits of random variation are given as ratio between two measurements. In the case of HR (supine), the ratios are .77 and 1.30. This means that the second measurement of an individual must increase at least by the factor 1.30 or be reduced by the factor .77 to attain a 95% confidence that a real change between two measurements has taken place. The ratios are considerably larger for time domain parameters (rMSSD > SDNN > CV), with a maximum of .31 and 3.20 for rMSSD (standing).

The greatest values within this index, and thus the lowest absolute reliability, are observed in the frequency domain parameters with lower limits ≤ .19 and upper limits ≥ 5.38. In this regard, the best case is LF/HF (supine) with 95% limits of random variation of .19 and 5.38; the worst case is HF (standing) with limits of .11 and 9.48. In the latter case, this means that an individual retest has to be approximately one tenth respectively ten times of the first measurement to be outside a 95% range of random variation.

Table 13

Absolute Reliability: Standard Error of Measurement (SEM) and Smallest Real Difference (SRD) across all Measurement Sessions and for the Paired Combinations with t1 (N = 103)

		All sessions		t1 × t2		t1 × t3		t1 × t4		t1 × t5	
Parameter	Posture	*SEM*	*SRD*	*SEM*	*SRD*	*SEM*	*SRD*	*SEM*	*SRD*	*SEM*	*SRD*
IBI (ms)	supine	83.34	231.02	83.41	231.21	84.28	233.62	93.47	259.08	74.35	206.10
	sitting	77.61	215.11	77.74	215.48	87.57	242.72	87.83	243.46	63.11	174.94
	standing	69.72	193.27	67.22	186.33	72.78	201.74	75.43	209.08	64.50	178.77
ln HR (ln bpm)	supine	0.09	0.26	0.09	0.26	0.10	0.27	0.11	0.29	0.08	0.23
	sitting	0.10	0.27	0.10	0.27	0.11	0.30	0.11	0.31	0.08	0.23
	standing	0.10	0.29	0.10	0.29	0.11	0.31	0.11	0.31	0.10	0.27
ln SDNN (ln ms)	supine	0.32	0.88	0.28	0.78	0.34	0.93	0.32	0.89	0.29	0.80
	sitting	0.29	0.81	0.31	0.87	0.31	0.86	0.29	0.81	0.28	0.79
	standing	0.29	0.81	0.27	0.76	0.29	0.80	0.30	0.83	0.30	0.82
ln rMSSD (ln ms)	supine	0.41	1.12	0.36	0.99	0.40	1.11	0.48	1.32	0.39	1.08
	sitting	0.41	1.13	0.38	1.06	0.41	1.14	0.45	1.26	0.39	1.08
	standing	0.42	1.16	0.39	1.08	0.41	1.15	0.43	1.19	0.42	1.16
ln CV (ln %)	supine	0.26	0.72	0.24	0.68	0.26	0.71	0.28	0.77	0.25	0.70
	sitting	0.24	0.67	0.26	0.73	0.25	0.70	0.23	0.64	0.25	0.70
	standing	0.23	0.64	0.20	0.56	0.23	0.64	0.23	0.65	0.24	0.66
ln HF (ln ms^2)	supine	0.75	2.09	0.67	1.84	0.76	2.12	0.86	2.39	0.74	2.04
	sitting	0.79	2.18	0.77	2.14	0.77	2.13	0.87	2.40	0.77	2.14
	standing	0.81	2.25	0.75	2.09	0.80	2.23	0.71	1.97	0.85	2.36
ln LF (ln ms^2)	supine	0.70	1.93	0.70	1.94	0.77	2.14	0.69	1.93	0.66	1.82
	sitting	0.61	1.70	0.68	1.90	0.65	1.79	0.64	1.78	0.67	1.87
	standing	0.64	1.77	0.61	1.68	0.62	1.72	0.67	1.86	0.63	1.76
ln LF/HF	supine	0.61	1.68	0.63	1.75	0.62	1.73	0.69	1.91	0.62	1.71
	sitting	0.61	1.69	0.59	1.62	0.63	1.75	0.67	1.85	0.59	1.63
	standing	0.66	1.84	0.64	1.76	0.59	1.63	0.71	1.98	0.54	1.49
ln TP (ln ms^2)	supine	0.66	1.84	0.60	1.67	0.69	1.90	0.71	1.97	0.63	1.75
	sitting	0.61	1.70	0.66	1.84	0.64	1.78	0.66	1.83	0.63	1.75
	standing	0.63	1.75	0.56	1.56	0.59	1.62	0.60	1.67	0.62	1.73

Notes. CV = coefficient of variation IBIs; HF = high frequency; HR = heart rate; IBI = interbeat interval; LF = low frequency; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power; t1 – t5 = time of measurement.

Table 14

Absolute Reliability: 95% Limits of Random Variation as Ratio between Two Measurements across all Measurement Sessions and for the Paired Combinations with t1 (N = 103)

		95% Limits of random variation as ratio between two measurements				
Parameter	Posture	All sessions	t1 × t2	t1 × t3	t1 × t4	t1 × t5
HR	supine	.77, 1.30	.77, 1.30	.76, 1.31	.75, 1.34	.79, 1.26
	sitting	.76, 1.31	.77, 1.30	.74, 1.35	.74, 1.36	.79, 1.26
	standing	.75, 1.34	.75, 1.33	.73, 1.36	.73, 1.36	.76, 1.32
SDNN	supine	.42, 2.41	.46, 2.18	.39, 2.55	.41, 2.44	.45, 2.23
	sitting	.44, 2.25	.42, 2.38	.42, 2.37	.44, 2.26	.46, 2.20
	standing	.44, 2.25	.47, 2.13	.45, 2.23	.44, 2.29	.44, 2.28
rMSSD	supine	.33, 3.08	.37, 2.70	.33, 3.04	.27, 3.73	.34, 2.94
	sitting	.32, 3.09	.35, 2.88	.32, 3.12	.28, 3.53	.34, 2.94
	standing	.31, 3.20	.34, 2.95	.32, 3.15	.31, 3.27	.31, 3.19
CV	supine	.49, 2.06	.51, 1.96	.49, 2.03	.46, 2.16	.50, 2.01
	sitting	.51, 1.96	.48, 2.08	.50, 2.01	.53, 1.90	.50, 2.02
	standing	.53, 1.90	.57, 1.75	.53, 1.89	.52, 1.91	.52, 1.93
HF	supine	.12, 8.08	.16, 6.33	.12, 8.33	.09, 10.94	.13, 7.67
	sitting	.11, 8.82	.12, 8.52	.12, 8.41	.09, 11.02	.12, 8.49
	standing	.11, 9.48	.12, 8.07	.11, 9.31	.14, 7.16	.09, 10.59
LF	supine	.15, 6.87	.14, 6.97	.12, 8.46	.15, 6.86	.16, 6.14
	sitting	.18, 5.46	.15, 6.67	.17, 6.00	.17, 5.92	.15, 6.49
	standing	.17, 5.89	.19, 5.38	.18, 5.56	.16, 6.40	.17, 5.79
LF/HF	supine	.19, 5.38	.17, 5.76	.18, 5.64	.15, 6.74	.18, 5.52
	sitting	.18, 5.43	.20, 5.08	.17, 5.77	.16, 6.37	.20, 5.12
	standing	.16, 6.28	.17, 5.82	.20, 5.11	.14, 7.22	.23, 4.42
TP	supine	.16, 6.30	.19, 5.29	.15, 6.72	.14, 7.19	.17, 5.75
	sitting	.18, 5.49	.16, 6.29	.17, 5.91	.16, 6.22	.17, 5.74
	standing	.17, 5.76	.21, 4.77	.20, 5.07	.19, 5.31	.18, 5.62

Notes. 95% limits of random variation for initially log-transformed parameters. To obtain a 95% confidence that a real change has taken place within an individual, an observed ratio between two measurements should be outside these limits (Pinna et al., 2007). CV = coefficient of variation of IBIs; HF = high frequency; HR = heart rate; IBI = interbeat interval; LF = low frequency; LF/HF = ratio of LF and HF; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power; t1 – t5 = time of measurement.

In conclusion, the most reliable parameter to be found in our study is HR, followed by CV and SDNN. In contrast, HF, LF, TP, and LF/HF show especially high random variations. Note that the estimated ratios do not differ systematically between the three postures. For example, 95% limits of random variation are lower for supine measurements of HF and LF/HF as compared to the other two postures. On the downside, CV shows lower limits for standing measurements as compared to supine and sitting measurements. For HR, SDNN, and rMSSD the ratios are almost identical for all postures.

The analyses of temporal changes of absolute reliability do not yield a systematic trend (see Tables 13 and 14). By and large, the 95% limits of random variation for HR, SDNN, rMSSD, and CV seem to be independent of the time interval between the measurements and remain relatively constant. Although the ratios of the frequency domain parameters vary more strongly over time, no clear temporal trend is obtained. For example, the ratio of HF (supine) between t1 and t5 (.13, 7.67) is smaller than the ratio between t1 and t4 (.09, 10.94) or between t1 and t3 (.12, 8.33). The same is true for the supine measurements of LF, LF/HF, and TP. In this vein, the indices of absolute reliability calculated across all measurement sessions appear to be good estimates of the extent of random variation between two measurements that have a temporal distance of at least two months.

3.4. Discussion

The present study has dealt with moderate- and long-term test-retest reliability of short-term HRV measurements as well as the influence of subjects' posture on such reliability indices. We took great care to conform to generally accepted recommendations for HRV measurements (Quintana et al., 2016; Task Force, 1996) as well as to current standards for reliability analyses (e.g., Atkinson & Nevill, 1998; Baumgartner, 1989; Bland & Altman, 1996a; Pinna et al., 2007; Sandercock, 2007; Sandercock et al., 2005; Weir, 2005). Given the comprehensive use of short-term HRV measurements for various research questions and clinical practice (Dong, 2016; Francesco et al., 2012; Makivić et al., 2013; Pinna et al., 2007; Sammito et al., 2015; Sandercock, 2007), the question arises whether HRV measurements actually lend themselves to a detection of changes over time (i.e., changes attributable to any kind of treatment). As noted by Sandercock and colleagues (2005), HRV can not be considered as a time-stable and (test-retest) reliable individual measure in general. This point of view is confirmed when considering the large amount of random variation within subjects we observed in the present study. As this is a far-reaching conclusion, let us discuss the specific results in more detail.

3.4.1. Test-Retest Reliability of Short-Term Heart Rate Variability

3.4.1.1. Relative Reliability

Compared to the majority of studies (e.g., Bertsch et al., 2012; Carrasco, González, Gaitán, & Yáñez, 2003; Cipryan & Litschmannova, 2013, 2014; Dietrich et al., 2010; Guijt et al., 2007; Hallman et al., 2015; Kobayashi, 2009; Kowalewski & Urban, 2004; Maestri et al., 2009; Pinna et al., 2007; Schroeder et al., 2004; Sinnreich, Kark, Friedlander, Sapoznikov, & Luria, 1998; Young & Leicht, 2011), our results suggest lower relative reliability with respect to the calculated *ICC*s (supine: .49 to .64, sitting: .40 to .57, standing: .35 to .56). In addition, the relative reliabilities of time domain and frequency domain parameters differ only marginally. Comparatively low relative reliability of time and frequency domain parameters is also reported by Pitzalis and others (1996), although their experimental conditions differ from ours (e.g., concerning the analysis interval used). Hence, we can safely conclude that for many parameters, a large proportion of the observed variance is attributable to random error (Pinna et al., 2007; Weir, 2005). There are several potential reasons for these results.

First, *ICC*s increase with sample heterogeneity (Atkinson & Nevill, 1998; Pinna et al., 2007; Shrout & Fleiss, 1979; Weir, 2005). Possibly, our relatively homogeneous sample produces a comparatively low between-subject variability (although it is known that there are large HRV-differences between individuals; Pinna et al., 2007). Second, the comparatively large time intervals between measurements (e.g., as compared to Cipryan & Litschmannova, 2013, 2014; Guijt et al., 2007; Maestri et al., 2009; Pinna et al., 2007) might lead to lower *ICC*s. However, other studies investigating longer time intervals between test and retest still report higher *ICC*s (Hallman et al., 2015; Kowalewski & Urban, 2004). Moreover, the magnitude of the *ICC*s in our study is not influenced by the time interval between test and retest. Finally, as various *ICC* calculation models lead to highly similar results, the obtained data pattern cannot be due specific statistical characteristics of our study. The most likely reason for our specific data pattern is that the error variance (i.e., the EMS) is comparably large in our data (as one can see from the *ICC*-equation; Shrout & Fleiss, 1979). This is in line with the presence of large *SEM*s. Of course, several causes of these data patterns are conceivable, such as different experimental conditions (e.g., with regard to the used ECG, analysis software, daytime of measurements) or the fact that we did not remove statistical outliers. While some authors report that outliers were removed according to a pre-defined cut-off (Cipryan & Litschmannova, 2013, 2014; Maestri et al., 2009; Pinna et al., 2007), we only corrected values due to typing errors or artefacts. Although outliers can affect reliability indexes (Maestri et al., 2009), in our opinion, there is no good reason to exclude logical and apparently correct values after log-transformation (for a more detailed discussion of this point, see Field, 2009). Furthermore, note that removing outliers potentially results in an overestimation of reliability.

3.4.1.2. Absolute Reliability

Our results suggest a considerable amount of random variation, which is particularly evident for the frequency domain parameters. This becomes especially clear after back-transformation of the initially log-transformed parameters (for details, see Atkinson & Nevill, 1998; Bland & Altman, 1996c, 1999, 2010; Pinna et al., 2007). For example, when considering HF (supine), the second measurement has to increase by more than 708 %, or has to be reduced by more than 88 % to attain a 95% confidence that a real change between two measurements has taken place. In a similar vein, all other frequency parameters (LF, LF/HF, TP) also reveal large random errors (95% limits of random variation: ≤ .19, ≥ 5.38). Time domain parameters show a comparatively better absolute reliability: Highest reliability is obtained for CV (standing) with limits of .53 and 1.90, and lowest reliability for rMSSD (standing) with limits of .31 and 3.20. The ratios for time domain parameters remain relatively constant regardless of kind of posture. Consequently, CV seems to be the most reliable HRV parameter in terms of absolute reliability. This result is in line with the findings of others, since the standardization of HRV parameters with respect to heart rate (IBI respectively) tends to improve the reproducibility of HRV measurements (Sacha, 2014; Sacha, Sobon, et al., 2013). Lowest ratios are observable for HR, which is strictly speaking no HRV parameter. Interestingly, HR reveals both lowest *ICC*s and smallest *SEM*s. This points to a low between-subject variance for HR and illustrates the limited interpretability of *ICC*s again.

A high degree of random variation in HRV parameters is also reported by other authors, and this is apparent even for repeated measurements with very short time intervals between test and retest (Cipryan & Litschmannova, 2013, 2014; Maestri et al., 2009; Pinna et al., 2007). Furthermore, there are some studies revealing high *SEM*s for log-transformed HRV parameters.

However, the authors did not back-transform the indices (Dietrich et al., 2010; Hallman et al., 2015; Pitzalis et al., 1996), likely leading to an overestimation of absolute reliability. In comparison to the above-mentioned studies, our results show a somewhat higher degree of random variation, possibly due to deviations in the study protocol (e.g., longer time intervals between measurements), or, with regard to the frequency domain parameters, as a result of the method used for spectral analysis. While other authors use more common methods of spectral analysis, such as Fast Fourier Transform or the autoregressive method (e.g., Cipryan & Litschmannova, 2013, 2014; Maestri et al., 2009; Pinna et al., 2007), our data are based on the Trigonometric Regressive Spectral Analysis (Rüdiger et al., 1999; Ziemssen et al., 2013). However, abnormal beats or artefacts have most likely not significantly affected our data since all interbeat interval series were visually checked and manually edited. To our knowledge so far, no study on reliability of HRV measurements exists using this kind of spectral analysis.

According to Maestri and others (2009) there are three potential sources of high within-subject variability: The susceptibility of the HRV parameters due to uncontrollable factors affecting the autonomic nervous system (e.g., emotions, mood, vigilance), the sampling variability of the HRV estimates, and the variation due to respiration changes (see also Pinna et al., 2007; Pinna, Maestri, & Di Cesare, 1996; Pinna, Maestri, La Rovere, Gobbi, & Fanfulla, 2006). As discussed below, these influences are partly uncontrollable, even when the second measurement immediately follows the first measurement, without any interruption (Cipryan & Litschmannova, 2013). In this light, the question arises whether HRV rather reflects the actual state of an individual, and not so much a dispositional trait (or an interaction of both). A very interesting study by Bertsch and colleagues (2012) indicates that about 40 % of the parasympathetic HRV variance of a single measurement is attributable to the situation and the interaction of person and situation. Furthermore, the authors suggest that a combination of two or more measurements might increase the proportion of assessed trait variance considerably. This finding may be of crucial importance for many research questions as well as for individual diagnosis.

3.4.1.3. Influences of Posture and Time Interval

It is well known that the magnitudes of HR and HRV parameters are decisively influenced by the subjects' posture during measurement (Acharya et al., 2005; Cipryan & Litschmannova, 2013; Dietrich et al., 2010; Kowalewski & Urban, 2004; Mahananto et al., 2015; Radhakrishna et al., 2000; Vuksanovic et al., 2005; Young & Leicht, 2011). These differences are also evident in our data. However, in accordance with other authors (Carrasco et al., 2003; Cipryan & Litschmannova, 2013, 2014; Dietrich et al., 2010; Kowalewski & Urban, 2004; Young & Leicht, 2011), we can not conclude that the extent of test-retest reliability systematically varies between postures. While relative reliability of HR and HRV parameters tends to be slightly higher for supine (*ICC*s ranging from .49 to .64) as compared to sitting (*ICC*s: .40 to .57) and standing (*ICC*s: .35 to .56), there is no clear trend with respect to absolute reliability. Here, highest *SEM*s (i.e., lowest absolute reliability) are observable for SDNN, CV, LF, and TP in the supine condition, while HR, rMSSD, HF, and LF/HF show largest *SEM*s for standing measurements.

Moreover, our results suggest that relative and absolute reliability are not systematically affected by the time interval between test and retest, with a minimum time interval of about two months (t1 vs. t2) and a maximum of about eleven months (t1 vs. t5). To put it simply: Reliability does not systematically decrease with an increasing time interval between two measurements. This finding is in line with the conclusion of Hallman and others (2015). In this vein, the reliability indices calculated across all measurement sessions appear to be good estimates for the reliability between two measurements that have a temporal distance of at least two months and maximally eleven months.

Regardless of time interval and posture, the 95% limits of random variation suggest a parameter-specific extent of random variability. A ranking in descending order of reliability looks like this: HR > CV > SDNN > rMSSD > LF/HF > TP > LF > HF.

3.4.2. Limitations

Some limitations of the present study should be mentioned. First, we excluded three HRV parameters (pNN50, LF nu, HF nu) from further analyses, as their properties seemed to be unsuitable for our intended reliability calculations. Independent of different data transformation attempts, serious distribution problems as well as heteroscedasticity remained unchanged for all measurement sessions (especially for sitting and standing measurements). Fortunately, pNN50 as a time domain parameter representing parasympathetic activity is also assessed by other variables, namely by rMSSD in the time domain and HF in the frequency domain (Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; Cygankiewicz & Zareba, 2013; Eller-Berndl, 2015; Nunan et al., 2010; Shaffer et al., 2014; Task Force, 1996). Also note that Hallman and others (2015) report that "pNN50 showed much poorer reliability than rMSSD and HF" (p. 810) resulting in the recommendation to prefer HF and rMSSD for the investigation of parasympathetic influences. In addition, LF nu and HF nu are the normalized units of LF and HF and therefore transformed expressions of the analysed frequency bands. LF nu and HF nu are linearly related to each other (HF nu = 1 – LF nu and vice versa), as well as mathematical related to LF/HF, implying redundancy between these three parameters (for a further discussion of this point, see Burr, 2007; Chemla et al., 2005; Heathers, 2014). For example, Cipryan and Litschmannova (2013) report a high degree of random variation for LF nu in the supine position and a comparatively lower extent of random variation in the standing position. As mentioned, the analysis of HF nu is not necessary when LF nu is analysed, since the results are redundant (Pinna et al., 2007).

A second limitation refers to the treatment of respiration effects, as our participants were instructed to breathe spontaneously. The strong influence of respiration on HRV is usually referred to as respiratory sinus arrhythmia (Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997, 1993; Eller-Berndl, 2015; Grossman & Taylor, 2007; Shaffer et al., 2014). There is still an ongoing debate on how to handle this influence (e.g., see Allen et al., 2007; Berntson et al., 1997; Denver et al., 2007; Grossman et al., 1991; Grossman & Taylor, 2007; Hirsch & Bishop, 1981; Ritz, 2009; Ritz et al., 2001). Although effects of paced breathing on reliability of HRV parameters seem to be only small and partly inconsistent (Bertsch et al., 2012; Kobayashi, 2009; Maestri et al., 2009; Pinna et al., 2007), we can not preclude that respiratory irregularities have produced further error variance to the spectral parameters (Dietrich et al., 2010; Grossman & Taylor, 2007).

Furthermore, to investigate temporal trends, we calculated reliability indices for all paired combinations with t1. One might argue that many more combinations of two, three, or four measurements are possible. For reasons of clarity and the expected informative value, we have refrained from analysing more combinations.

Unfortunately, due to the high organisational effort, it was not possible to provide a constant time interval between measurements for all subjects. However, it seems that this factor has not significantly affected our test-retest reliabilities (see also Cipryan & Litschmannova, 2013). This assumption is supported by the results concerning temporal trends of reliability indices. In this vein, it must be noted that HRV recordings took place at different times of day. Given circadian influences on HRV (e.g., Bilan et al., 2005; Boudreau et al., 2012; Eller-Berndl, 2015; Guo & Stein, 2002; Huikuri et al., 1990; Pumprla et al., 2002), this could have affected the reliability indices. However, there is a high interindividual variance of circadian rhythms (Refinetti, 2016), which considerably complicates the investigation of this factor.

Similarly, the randomization of the posture sequence might be a potential limitation. Although we made sure that position changes were carried out very slowly (within about two minutes) to prevent unintended physiological responses such as orthostatic stress (e.g., see Ziemssen, Süss, & Reichmann, 2002), it can not be excluded that this has affected test-retest reliability. To assess the influence of this variable, an additional study is needed which does not use this type of randomization.

Finally, a note of caution is warranted concerning the generalizability of our results, as we investigated reliability on a student sample with relatively homogenous demographic characteristics (e.g., sex, age, consumption patterns, educational level, physical activity, health status). This restriction of generalizability is particularly important with respect to age and sex of the subjects, as these variables are known to affect HRV (Abhishekh et al., 2013; Agelink et al., 2001; Almeida-Santos et al., 2016; Antelmi et al., 2004; Eller-Berndl, 2015; Fagard et al., 1999; Koenig & Thayer, 2016; Voss et al., 2015; Young & Leicht, 2011; Zhang, 2007). In the present study, we investigated a comparatively young sample (M = 21.72, SD = 3.31, with a range from 18 to 35 years) that to a large part consisted of female subjects (n = 83). However, it is important to note that reliability indices for men versus women do not differ substantially (in part, there are marginally better indices for women).

3.4.3. Conclusions and Future Research

Our results indicate that short-term HRV analysis, a widely-used approach for the assessment of autonomic functioning (see Chapter I), seems to be associated with large random variation from test to retest. This is especially true for frequency domain parameters. According to our data, *ICC*s are smaller as expected from previous literature, indicating that a large proportion of the observed variance is attributable to random error (Pinna et al., 2007; Weir, 2005). Effects of subjects' posture and time between measurements on reliability are small and largely unsystematically. An obvious conclusion might be that HRV measurements are of limited use to reveal individual changes and treatment effects over time. Furthermore, we might thus ask whether a popular assumption of HRV research is warranted – namely, that this system is a reliable, stable, and trait-like characteristic of human functioning. Given the high complexity and dynamic of the underlying biological processes and influences (Fatisson et al., 2016; Shaffer et al., 2014), previous researchers may have – at least partially – overestimated the dispositional nature of HRV and its indicators (e.g., Porges, 1995b, 2001, 2007, Thayer & Lane, 2000, 2009).

In this vein, note that with decreasing reliability, the required sample sizes to detect real changes between two measurements increase (Pinna et al., 2007). Hence, parameters of interest with worst reliability and expected treatment effects dictate necessary experimental designs and required sample sizes (such sample size estimations were carried out by Cipryan & Litschmannova, 2013, 2014; Dietrich et al., 2010; Hallman et al., 2015; Maestri et al., 2009; Pinna et al., 2007).

It is difficult to attribute the large within-subject variance to a single factor. However, among other factors, uncontrollable internal states of the subjects are a likely source. In addition, difficult-to-control external factors may play a role as well. A review by Fatisson and others (2016) has suggested five superordinate categories of influences: physiological and pathological influences (e.g., respiration, thermoregulation, diseases), neuropsychological influences (e.g., mood, stress), lifestyle factors (e.g., tobacco, physical activity), non-modifiable person characteristics (e.g., age, gender), and environmental factors (e.g., electromagnetic fields). In this light, there obviously are various influences on HRV, which are also likely to affect each other (see also Chapter II).

Chapter IV

4. Stress and Coping in School

Heart Rate Variability, Self-Reported Stress, and School Achievement

Uhlig, S.[1], Winter, N.[2], Meylan, A.[1], & Rudolph, U.[1]

[1]*Chemnitz University of Technology, General Psychology and Biopsychology*

[2]*Integratives Zentrum zur Förderung hyperkinetischer Kinder, Chemnitz*

Abstract

The present study analyses the relationships between self-reported stress, coping strategies, HRV, and school achievement, based on a cross-sectional study with *N* = 72 high school students (fifth to eighth grade; ten to 15 years, *M* = 12.65, *SD* = 1.21, *n* = 41 females). We assessed stress and coping (SSKJ 3-8; Lohaus et al., 2006), short-term measurements of heart rate variability (HRV), and pupils' grade point averages (GPA) as an indicator of school achievement. Based on bivariate correlation analyses, we computed multiple linear regressions, to predict pupils' physical and psychological stress symptoms as well as their overall GPA. Analyses reveal that stress vulnerability, problem-focused coping, psychological symptoms, and overall GPA are significant predictors of physical stress symptoms (R^2 = .58; R_a^2 = .54, p < .001). Moreover, stress vulnerability, seeking social support, destructive-anger-related emotion regulation, physical stress symptoms, and low-frequency HRV predict psychological stress symptoms (LF; R^2 = .53; R_a^2 = .48, p < .001). Finally, overall GPA is predicted by problem-focused coping, physical stress symptoms, and the low- to high-frequency HRV ratio (R^2 = .27; R_a^2 = .21, p < .001). Associations between stress, coping, and school achievement are well in line with previous research. However, HRV indices do not contribute to these predictions. Implications arising from these data patterns are discussed.

Keywords: stress, coping, school achievement, heart rate variability, pupils

4.1. Introduction

Stress research is an extremely broad and intensively investigated field, with various disciplines involved, such as medicine, psychology, biology, physiology, and engineering sciences (see also Glanz & Schwartz, 2008; Krohne, 2001). Hence, there is no such thing as a generally accepted and comprehensive theory of stress and coping with stress (e.g., see Berntson & Cacioppo, 2004; Compas, Connor-Smith, Saltzman, Thomsen, & Wadsworth, 2001; Hobfoll, 1989; Krohne, 2017; Morgenroth, 2015). As has already been pointed out, we might distinguish stimulus- or environment-related theories, as well as response-related and transactional approaches (for overviews, see also Brannon, Feist, & Updegraff, 2014; S. Cohen, Kessler, & Gordon, 1995). Another important distinction within stress research is related to the effects of stress, differentiating between positive, healthful stress (eustress) on one hand, and negative, damaging stress on the other hand (distress; e.g., see Lazarus, 1993; Pinel & Pauli, 2017; Selye, 1974, 1976). The multitude of conceptual approaches corresponds to a high diversity within the methodology for stress and coping assessments. This includes questionnaire methods (for overviews, see Compas et al., 2001; Franke, Jagla, Salewski, & Jäger, 2007), physiological markers of stress, and behavioural outcomes of coping with stress (for overviews, see Krohne, 2017; Oken et al., 2015). Among the physiological markers of stress, short-term measurements of heart rate variability (HRV) are a comparatively new development. In this vein, HRV is regarded as a non-invasive and auspicious biomarker for different kinds of stress/stressors (see also Berntson & Cacioppo, 2004; Chandola et al., 2010; Michels, Sioen, et al., 2013; Pumprla et al., 2002).

It is assumed that HRV can shed light on the functional capacity of the autonomic nervous system: The autonomic modulation of the heart rate is - by and large – a composition of inhibitory effects of the parasympathetic nervous system (PNS), and excitatory influences of the sympathetic nervous system (SNS), both influencing the sinostrial node of the heart (Appelhans & Luecken, 2006; Berntson et al., 1997; Cygankiewicz & Zareba, 2013; Hoyer, 2009; Shaffer et al., 2014; Stein & Kleiger, 1999; Task Force, 1996). Accordingly, HRV may be indicative of the psychological and physiological ability to cope with continuous situational requirements (e.g., Appelhans & Luecken, 2006; Beauchaine, 2001; McCraty et al., 1995; Porges, 1995b, 2001; Quintana & Heathers, 2014; Shaffer et al., 2014; Thayer & Lane, 2000). According to previous research, high HRV is commonly related to desirable outcomes, while low HRV values are associated with adaptive and health difficulties (for overviews, see Appelhans & Luecken, 2006; Beauchaine & Thayer, 2015; Cygankiewicz & Zareba, 2013; Riganello et al., 2012). Studies on children and adolescents also provide evidence that HRV and measures of well-being or mental health are associated, as for example for adolescents' depressive symptoms (e.g., Vazquez et al., 2016), anxiety disorders (e.g., R. K. Sharma, Balhara, Sagar, Deepak, & Mehta, 2011), and children's subjective perceptions of stress (Michels, Sioen, et al., 2013).

In the present study, we investigate subjective stress experiences of children and adolescents within the school environment. Specifically, we identify stress vulnerability, stress-related symptoms, and individual coping strategies. In addition, we explore relationships between stress, HRV as an indicator of emotion regulation (Appelhans & Luecken, 2006), and school achievement.

4.1.1. Stress and Coping Strategies at School

Of course, there are various sources of stress in school (Seiffge-Krenke, 2008), among them conflicts between peers (e.g., aggression; see also Seiffge-Krenke & Welter, 2008), conflicts with parents and teachers (e.g., due to communications of high levels of aspiration), achievement-related demands (e.g., performance pressure, test anxiety), and school transitions (especially from primary to high school). According to Seiffge-Krenke and Skaletz (2006), highest subjective stress levels arise especially from future-related worries, followed by school-related stressors, stress with friends, stress with parents, identity stress, and stress resulting from romantic relationships. A comparison of different educational systems in a large number of countries reveals that perceived school stress of German adolescents seems to be neither particularly high nor strikingly low (see Seiffge-Krenke, 2006).

In addition, coping strategies of pupils are significantly influenced by gender: Girls are more likely to engage in problem-focussed coping and to seek for social support, while boys have a higher likelihood of avoidant coping (Beck, Lange, & Tröster, 2016; Eschenbeck, 2010; Eschenbeck, Kohlmann, & Lohaus, 2007). These trends are more pronounced in case of social as compared to achievement-related stressors. Surprisingly, coping strategies are not much influenced by the age of the pupils. It seems that younger pupils may tend to engage more in avoidant strategies as compared to older pupils, who tend to report more problem-focussed and emotion-regulating coping patterns. However, these are only small effects (for an overview, see also Eschenbeck, 2010). Furthermore, there are small gender effects with respect to self-reported stress vulnerability as well as perceptions of physical and psychological symptoms, with lower scores for boys (Beck et al., 2016; Lohaus, Beyer, & Klein-Heßling, 2004). Finally, psychological stress symptoms (such as anger, exhaustion, anxiety, sadness) increasing with grade level (Lohaus et al., 2004).

4.1.2. Stress, Coping, and School Achievement

Stress (especially chronic stress) has pronounced negative effects on cognitive performance (e.g., see Chrousos, 2009; Lupien, Maheu, Tu, Fiocco, & Schramek, 2007; McEwen & Sapolsky, 1995). In a similar vein, there is a negative association between self-reported stress and school achievements in terms of grades and grade point averages (GPA). This is confirmed by cross-sectional (e.g., Cunningham, Hurley, Foney, & Hayes, 2002; Gillock & Reyes, 1999; Levitt, Guacci-

Franco, & Levitt, 1994) and longitudinal data (e.g., D. S. Kaplan, Liu, & Kaplan, 2005; Stewart, Lam, Betson, Wong, & Wong, 1999). Furthermore, there are negative associations between emotion-focussed or avoidant coping and GPA as well as positive associations between problem-focussed coping and GPA (e.g., Brdar, Rijavec, & Loncaric, 2006; Causey & Dubow, 1992; Compas et al., 2001; MacCann, Fogarty, Zeidner, & Roberts, 2011; Weis, Heikamp, & Trommsdorff, 2013; Windle & Windle, 1996).

4.1.3. Stress, Coping, and HRV

Physiological responses to stress in humans are essentially based on the activity of two neuroendocrine systems (e.g., see Charmandari, Tsigos, & Chrousos, 2005; Chrousos, 2009; Gunnar & Quevedo, 2007; Krohne, 2017; Michels, Sioen, et al., 2013; Oken et al., 2015; Pinel & Pauli, 2017; Schandry, 2016), the hypothalamus-pituitary-adrenal (HPA) axis and the autonomic nervous system (sympathetic adrenomedullary axis, SAM). Activation of the HPA axis triggers the hypothalamic corticotropin-releasing hormone (CRH), stimulating the pituitary gland to produce the adrenocorticotropic hormone (ACTH). This in turn initiates the secretion of glucocorticoids (e.g., cortisol) from the adrenal cortex. As a consequence, the organism is supplied with energy (e.g., via glucose). Stressors also lead to an activation of the SAM axis, accompanied by SNS activation and PNS inhibition (see also Taelman, Vandeput, Spaepen, & Van Huffel, 2009), resulting in the secretion of the catecholamines epinephrine and norepinephrine from the adrenal spinal cord. As a result, heart rate and blood pressure increase, a reaction also known as fight-or-flight response (as introduced by Walter Cannon, 1929; see also Gunnar & Quevedo, 2007). As compared to the secretion of glucocorticoids, the release of catecholamines is much faster (see also McEwen & Sapolsky, 1995). Thus, stress overstraining the individual's adaptation possibilities (e.g., chronic stress, recurring daily hassles) seems to have harmful effects over time

(Charmandari et al., 2005; Gunnar & Quevedo, 2007; Oken et al., 2015; Schandry, 2016; Taelman et al., 2009).

As mentioned above, HRV may be seen as an indicator of the human stress response (Chandola et al., 2010; Krohne, 2017; Michels, Sioen, et al., 2013; Oken et al., 2015; Porges, 1995a; Pumprla et al., 2002), although the current situation is far from clear (see also Berntson & Cacioppo, 2004). A typical pattern in response to stress is accompanied by increasing SNS activity (i.e., higher levels of low frequency power, LF), decreasing PNS influence (i.e., lower levels of high frequency power, HF), and occasionally higher values of the LF/HF quotient (Berntson & Cacioppo, 2004). Such data patterns have been (partly) observed for a diverse range of stressors, such as pressing stressors under controlled laboratory conditions (e.g., Stroop test, cognitively demanding tasks; Delaney & Brodie, 2000; Hansen et al., 2009; Hjortskov et al., 2004), stressors of everyday life (e.g., workplace stressors or university examinations; Chandola et al., 2010; Jarczok et al., 2013; Matthews, Jelinek, Vafaeiafraz, & McLachlan, 2012; Papousek et al., 2010), and overall self-reported stress (e.g., Dishman et al., 2000; Lucini et al., 2005).

Thus far, there are only few studies investigating the relationship between self-reported stress (and coping, respectively) and HRV among children and adolescents. Nevertheless, there is some evidence for similar stress patterns in HRV as described above, especially for self-reported anxiety in girls (Michels, Sioen, et al., 2013). Moreover, Fabes and Eisenberg (1997) report a positive relationship between vagal tone and constructive coping behaviour (i.e., problem-focused coping and support seeking) as well as a negative relationship between vagal tone and negative emotional arousal. O'Connor and others (2002) report negative associations between vagal tone and passive coping.

4.1.4. HRV and School Achievement

There are reliable data indicating associations between HRV and cognitive performance (e.g., see Duschek et al., 2009; Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004; Hansen et al., 2003; Luque-Casado et al., 2016; Shah et al., 2011; Thayer et al., 2009). In addition, there is some evidence that (a) vagal tone at rest is not associated with children's reading performance (Becker et al., 2012), (b) low- and high-performing adults (in terms of GPA) do not differ significantly with respect to HRV indices (K. S. Kim & Nam, 2010), (c) cognitive performance of high school students is improved by HRV biofeedback (Pop-Jordanova & Chakalaroska, 2008), and (d) children's attentional performance seems to be related to their vagal tone at rest (Suess et al., 1994). Hence, we would like to explore whether a more general relationship exists between HRV indices on one hand and school achievement on the other hand (e.g., in terms of GPA).

4.1.5. Aim of the Study

To summarize: (a) Children and adolescents are already exposed to considerable stress within and outside the school environment. (b) There is some evidence suggesting relationships between self-reported stress, coping strategies, and school achievement. (c) In general, stress and coping are accompanied by specific HRV patterns. (d) Studies analysing the relationship between perceived stress, coping, HRV, and achievement results are largely missing within an educational context.

Therefore, the aim of the present study is to examine the triad between stress/coping, HRV, and school performance. We will subsequently provide a first attempt in the course of a cross-sectional study. We are particularly interested as to whether HRV measurements predict pupils' stress symptoms and school achievement.

4.2. Methods and Materials

4.2.1. Participants

A total of N = 88 pupils of the “Freies Gymnasium Penig” participated in the study (n = 47 females; age range between ten and 15 years, with M = 12.61 and SD = 1.20). Within a group session, all pupils filled out a stress questionnaire. 79 of these pupils (n = 45 females, age range between ten and 15 years, with M = 12.55 and SD = 1.22) also participated at the subsequent HRV measurement. After carefully inspecting the questionnaires and ECG recordings, we excluded N = 7 pupils (four cases due to too many artefacts, two cases due to missing data, and one pupil due to a cardiovascular disease). Hence, the resulting sample consists of N = 72 pupils between ten and 15 years (M = 12.65, SD = 1.21, n = 41 females, from fifth to eighth grade; for an overview, see Table 15). We used a standardized questionnaire to assess health status, current medications, substance consumption (caffeine), and physical activity. The school GPA of each participant was collected at the end of the school year.

4.2.2. Ethical Statement

In conformity with the Declaration of Helsinki (World Medical Association, 2013), the present study has been assessed and approved by the local ethics committee of the Chemnitz University of Technology. Both pupils and their parents were informed in detail about the study content, procedures, and objectives. Participation in this study was only allowed upon written informed consent by both pupils and parents. Study participation was entirely voluntarily and could be cancelled at any time (without any further notice needed; non-participation was not associated with any disadvantages for the pupils). Potential questions or problems could be resolved at any time either in person or by using the contact details provided by the experimenter. Furthermore, parents were able to choose whether they would like to be informed about abnormal or norm-deviating test results of their children. To anonymize all data for further processing, each subject generated an individual participation code.

Table 15

Sample Characteristics

Variable	Female (*n* = 41)	Male (*n* = 31)	Total (*N* = 72)
Age, *M* ± *SD* (years)	12.56 (1.34)	12.77 (1.02)	12.65 (1.21)
Height, *M* ± *SD* (cm)	158.32 ± 7.47	164.19 ± 10.50	160.85 ± 9.30
Weight, *M* ± *SD* (kg)	46.67 ± 8.98	52.53 ± 10.39	49.19 ± 9.98
Body mass index, *M* ± *SD*	18.51 ± 2.67	19.45 ± 3.32	18.91 ± 2.98
GPA, *M* ± *SD*			
German as mother tongue	4.59 ± 0.71	4.58 ± 0.62	4.58 ± 0.67
Mathematics	4.71 ± 0.81	4.71 ± 0.59	4.71 ± 0.72
English as foreign language	4.59 ± 0.95	4.61 ± 0.96	4.60 ± 0.94
Overall	4.82 ± 0.48	4.80 ± 0.54	4.82 ± 0.51
Grade level, *n* (%)			
Fifth grade	9 (22)	3 (10)	12 (17)
Sixth grade	9 (22)	10 (32)	19 (26)
Seventh grade	5 (12)	9 (29)	14 (19)
eighth grade	18 (44)	9 (29)	27 (38)
Sport/no sport, *n* (%)	25 (61)/16 (39)	25 (81)/6 (19)	50 (69)/22 (31)
Up to 90 minutes a week	15 (60)	3 (12)	18 (36)
Up to 180 minutes a week	6 (24)	9 (36)	15 (30)
Up to 270 minutes a week	2 (8)	7 (28)	9 (18)
More than 270 minutes/week	2 (8)	6 (24)	8 (16)

Notes. Grade point averages (GPA) were collected at the end of the school year and represent inverted values (1 = *insufficient*, 6 = *very good*).

4.2.3. Material and Technical Equipment

4.2.3.1. Assessment of Perceived Stress Vulnerability, Coping, and Stress Symptoms

The *Questionnaire for the Measurement of Stress and Coping in Children and Adolescents* (SSKJ 3-8; Lohaus et al., 2006) is a standardized German self-assessment questionnaire, based on the transactional stress model (e.g., Lazarus, 1966; Lazarus & Cohen, 1977; Lazarus & Folkman, 1984; Lazarus & Launier, 1978) and subsequent scientific progress within the field of coping (e.g., Causey & Dubow, 1992; Compas et al., 2001). Within the inventory, children and adolescents from grades three to eight provide information about (a) their subjective perceived *stress vulnerability* (six items), (b) their *coping strategies* (2 x 30 items), and (c) their experience of *stress symptoms* (18 items). Thus, the SSKJ 3-8 combines trait-like (stress vulnerability, coping strategies) and state-like (stress symptoms) constructs.

For assessing stress vulnerability, participants indicate their degree of stress for everyday situations by using a 4-point rating scale (*no stress*, *low stress*, *much stress*, *very much stress*). Reliability analyses suggest a retest reliability of r_{tt} = .74 and a Cronbach's α of .66 (Lohaus et al., 2006). To assess coping strategies, participants imagine two different situations (dispute with a good friend, difficulties with doing homework), and subsequently indicate by using a 5-point rating scale (1 = *never*, 5 = *always*) how often a specific coping style is applied. Five coping strategies are assessed (see also Causey & Dubow, 1992; Eschenbeck, 2010; Eschenbeck et al., 2007; Eschenbeck, Kohlmann, Lohaus, & Klein-Heßling, 2006): (a) *seeking for social support*, (b) *problem-focussed coping*, (c) *avoidant coping*, (d) *constructive-palliative emotion regulation*, and (e) *destructive-anger-related emotion regulation*. Reliability analyses for the subscales indicate retest reliabilities from r_{tt} = .62 to r_{tt} = .82 and internal consistencies between α = .68 and α = .89 (Lohaus et al., 2006). In the present study, the sum scores of both situations were aggregated. Stress symptomatology is assessed with respect to *psychological* (twelve items; subscales are anger, sadness, and anxiety) and *physical symptoms* (six items; e.g., headache). Participants indicate how often they have experienced the symptoms in the previous week (3-point rating scale: *not once*, *once*, *several times*). Retest-reliabilities vary between r_{tt} = .56 and r_{tt} = .73, internal consistencies ranging between α = .71 and α = .87 (Lohaus et al., 2006).

4.2.3.2. ECG Data Recording and Processing

We used a three-clamp-electrode ECG system (SUEmpathy100; SUESS Medizin-Technik, Aue, Germany) to record the interbeat interval series for each subject by attaching disposable adhesive electrodes (Dahlhausen type 405, Ag/AgC1; 45 mm diameter) to the upper body of the pupils. Data were recorded with a sampling rate of 512 Hz and a resolution at 12 bit. Subsequently, we calculated HRV parameters offline by using the eponymous analysis software (see below).

After connecting participants to the ECG, it was ensured that R-peaks were clearly visible. Subjects were then instructed to assume the most pleasant supine position, to move as little as possible, to relax, and to breathe spontaneously (we did not record actual respiration). Each recording lasted about eight minutes to increase the probability of assessing an artefact-free analysis interval of five minutes (as recommended by the Task Force guidelines, 1996). As movements or respiratory irregularities can influence HRV parameters, the experimenter observed each participant during the entire recording. Potential disturbances were noted immediately and taken into account for subsequent artefact clean-up.

As a general rule, we analysed the five-minute interval between minute two and minute seven of the recording interval. Whenever artefacts became evident within this interval, we scanned the entire recording for an alternative artefact-free five-minute segment. After choosing the analysis interval, the interbeat interval series was visually inspected for artefacts and abnormal beats. These were manually edited if needed (see Task Force guidelines, 1996). This manual post-processing does not change the time reference within each recording.

In addition to the mean heart rate (HR) and the mean interbeat interval (IBI), we calculated time and frequency domain parameters. Note that time domain parameters represent descriptive statistics of the analysed time series (Appelhans & Luecken, 2006; Berntson et al., 1997; Eller-

Berndl, 2015; Shaffer et al., 2014; Stein & Kleiger, 1999). Frequency domain parameters (also called spectral components or frequency bands) result from a spectral analysis (with different methods available; e.g., Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; Hoyer, 2009; Shaffer et al., 2014; Stein & Kleiger, 1999; Task Force, 1996). In accordance with Task Force guidelines (1996), we calculated the following time domain parameters (see also Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; Eller-Berndl, 2015; Laborde et al., 2017; Shaffer et al., 2014): The standard deviation of the interbeat intervals (SDNN; in ms), the square root of the mean squared differences of consecutive interbeat intervals (rMSSD; in ms), the percentage of successive interbeat intervals with a difference larger than 50 ms (pNN50; in %), and the coefficient of variation of interbeat intervals (CV; in %; Ikawa et al., 2001).

The calculation of frequency domain parameters was based on the Trigonometric Regressive Spectral Analysis (for details on this method, see Rüdiger et al., 1999; Ziemssen et al., 2013). Taking the recommendations of the Task Force (1996) into account, we used the following parameters (for details, see Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1997; Cygankiewicz & Zareba, 2013; Eller-Berndl, 2015; Pumprla et al., 2002; Shaffer et al., 2014): The high frequency component (HF; 0.15 to 0.40 Hz; in ms^2), the low frequency component (LF; 0.04 to 0.15 Hz; in ms^2), the total power (TP; ≤ 0.40 Hz; in ms^2), the ratio of LF and HF (LF/HF), as well as HF and LF as normalized units (nu; HF nu = HF/(TP - VLF)×100; LF nu = LF/(TP - VLF)×100; Task Force, 1996). Due to the well-known unsuitability for short-term measurements (Task Force, 1996), we did not analyse the very low frequency component (VLF; ≤ 0.04 Hz; in ms^2). Overall, the conducted physiological measurements closely adhere to established guidelines for HRV measurements and their reporting (Laborde et al., 2017; Quintana et al., 2016; Task Force, 1996).

4.2.3.3. Assessment of School Performance

To obtain school performance indicators for each participant at the end of the school year, class teachers received a list with the participant codes. Subsequently, the pupils were asked to write their name in the column in front of their personal code. Thus, the teacher was able to add the respective English, mathematics, German, and overall GPA to the list. Upon completion of this procedure, the class teacher removed the column with the students' names and submitted the final list to the investigators. To improve the readability of the results, GPA scores were inverted (1 = *insufficient*, 6 = *very good*).

4.2.4. Study Protocol and Study Design

In a first step, all high school students were informed about content and course of the study during the so-called "class teacher lesson". After collecting the written informed consents from both parents and children, the pupils completed the SSKJ 3-8 (Lohaus et al., 2006) within a group session. Subsequently, individual appointments for HRV recordings were arranged as soon as possible. As a consequence, the time interval between group testing and HRV measurement varies between six days and 17 days (*Mdn* = 7.00, *M* = 9.97, *SD* = 3.94).

HRV measurements were carried out in the quiet medical room of the school at a comfortable temperature, and always between 9.00 am and 3.30 pm. Study conditions were kept as constant as possible. After arriving, participants were welcomed by the investigator and filled out a short demographic questionnaire. Then the participants were connected to the ECG, took a comfortable supine posture, and signalled the investigator their readiness to start. After the 8-minute recording, they were able to clean any adhesive residues. Each session lasted about 20 minutes. As all subjects went through the same study conditions, this is a within-subjects design.

4.2.5. Statistical Analyses

We screened all data for incorrect values, and corrected these by re-checking the pertaining individual dataset. Note that most HRV parameters are not distributed normally (as indicated by various significance tests and Q-Q plots). This problem is typically solved by computing the natural logarithm (ln; for example, see Bland & Altman, 1996c, 1999; Field, 2013; Hallman et al., 2015; Heathers, 2014; Kleiger et al., 1991; Laborde et al., 2017; Nunan et al., 2010; Pinna et al., 2007). For our data, log-transformation for pNN50 was not successful. As pNN50 is an index representing vagal tone, we excluded this parameter from further analyses. Fortunately, vagal tone is also assessed by other variables, namely by rMSSD and HF, and several sources recommend the use of rMSSD rather than pNN50 (e.g., Allen et al., 2007; Hallman et al., 2015; Kleiger et al., 2005; Laborde et al., 2017; Shaffer et al., 2014; Task Force, 1996). Moreover, we checked gender differences by using independent *t*-tests and Mann-Whitney-*U* tests, respectively (two-tailed, with $p < .05$; corresponding effect sizes will be reported as *d* or *r*).

To allow for a first data exploration, we report simple correlative statistics between self-reported aspects of stress, HRV parameters, and GPA. Due to the distribution properties of some variables, we will report parametric and non-parametric correlations (i.e., Pearson [*r*] and Spearman's correlation coefficients [r_s]).

Finally, we will present multiple linear regressions, to identify variables predicting self-reported stress symptoms and overall GPA. With respect to previous research, special consideration is given to stress vulnerability, coping strategies, physical and psychological stress symptoms (depending on the model as predictor or criterion), overall GPA (predictor or criterion), as well as the following HRV parameters: ln HF, ln LF, and ln LF/HF. These restrictions are also necessary to avoid redundancy and to reduce problems of multicollinearity (e.g., see Field, 2013).

Also note that the present sample size limits the number of potential predictors that can be entered into a regression analysis (e.g., see Field, 2009, 2013). Additionally, from previous literature we do not know with certainty, which predictors are most important in predicting the respective criterion. Therefore, we first consider (a) forced entry methods, which are then followed by (b) stepwise regressions (entry criterion: p = .05, removal criterion: p = .10) to identify predictors having predictive value within the model. Based on the results of the exploratory correlation analyses, predictors correlating less than r = .10 with the dependent variable will be excluded a priori to avoid suppressor effects (e.g., see Field, 2013). As a result, we present (c) multiple regressions (forced entry) including those predictors that substantially increase the predictive power of the model as indicated by significance level, standardized regression coefficient (β), partial correlation ($r_{ab,c}$), or semi-partial correlation ($r_{a(b.c)}$). Age and gender are used as control variables. All analyses were performed using IBM SPSS Statistics 24, G*Power (Faul, Erdfelder, Buchner, & Lang, 2009; Faul, Erdfelder, Lang, & Buchner, 2007), and MS Excel 2016.

4.3. Results

4.3.1. Descriptive Statistics and Gender Differences

Arithmetic means and standard deviations of all HRV raw values can be taken from Table 16. As all parameters except IBI, HR, HF nu, and LF nu are considerably skewed, we log-transformed (ln) these parameters, resulting in normally distributed data (see also Table 16). There are significant differences for HR and IBI between girls (M_{HR} = 86.74, SD = 13.84, SE = 2.16; M_{IBI} = 708.29, SD = 107.08, SE = 16.72) and boys (M_{HR} = 77.16, SD = 10.79, SE = 1.94; M_{IBI} = 794.00, SD = 123.43, SE = 22.17), with $t(70) = 3.19$, $p = .002$, $d_{HR} = 0.76$ and $t(70) = -3.15$, $p = .002$, $d_{IBI} = -0.75$. According to Cohen (1988), these are medium effect sizes. Although there are also small gender effects for some other HRV parameters (up to $d = -0.46$ and $t(70) = -1.95$, $p = .056$ for ln HF), these effects are not significant. Calculations using the software G*Power (Faul et al., 2009) reveal a necessary sample size of $N = 154$ for the reliable detection of effects of this magnitude (two-tailed, α = .05, power = .80, ratio of $n_2/n_1 = 0.76$).

Considering the statistics of the SSKJ 3-8 scales (Lohaus et al., 2006), the calculated internal consistencies vary considerably, ranging from Cronbach's α = .46 (stress vulnerability) to α = .90 (problem-focused coping; see Table 17). In addition, female and male pupils differ significantly according to their self-reported stress vulnerability (M_{girls} = 16.68, SD = 2.52, SE = 0.39; M_{boys} = 15.06, SD = 2.48, SE = 0.45), with $t(70) = 2.72$, $p = .008$, $d = 0.65$, seeking for social support (M_{girls} = 34.39, SD = 7.56, SE = 1.81; M_{boys} = 27.74, SD = 7.92, SE = 1.42), with $t(70) = 3.63$, $p < .001$, d = 0.86, and with respect to their perceived physical stress symptoms (M_{girls} = 9.63, SD = 2.56, SE = 0.40; M_{boys} = 8.29, SD = 2.55, SE = 0.46), with $t(70) = 2.21$, $p = .030$, $d = 0.53$.

Table 16

Descriptive Statistics and Gender Differences for HR(V) Parameters: Raw Values and log-Transformed Data (N = 72)

Parameter	Female (n = 41)	Male (n = 31)	Total (N = 72)	t-test / Mann-Whitney-U		
	M (SD)	M (SD)	M (SD)	t / U (z)	d / r	[95% CI]
[a]IBI in ms	708.29 (107.08)	794.00 (123.43)	745.19 (121.34)	-3.15**	-0.75	[-0.27, -1.23]
[a]HR in bpm	86.74 (13.84)	77.16 (10.79)	82.62 (13.41)	3.19**	0.76	[0.28, 1.24]
SDNN in ms	49.62 (21.08)	57.04 (21.94)	52.82 (21.62)	510 (-1.43)	-.17	[.06, -.41]
rMSSD in ms	44.62 (30.57)	54.38 (30.48)	48.83 (30.70)	495 (-1.60)	-.19	[.04, -.43]
CV in %	6.84 (2.21)	7.12 (2.31)	6.96 (2.24)	594 (-0.47)	-.06	[.18, -.30]
HF in ms^2	1016 (1252)	1361 (1312)	1164 (1281)	482 (-1.75)	-.21	[.02, -.45]
[a]HF nu in %	46.58 (14.77)	52.06 (13.31)	48.94 (14.33)	-1.63	-0.39	[0.08, -0.86]
LF in ms^2	938.75 (952.18)	1235 (1221)	1066 (1078)	553 (-0.94)	-.11	[.13, -.35]
[a]LF nu in %	53.42 (14.77)	47.94 (13.31)	51.06 (14.33)	1.63	0.39	[-0.08, 0.86]
LF/HF	1.38 (0.97)	1.07 (0.64)	1.25 (0.86)	501 (-1.53)	-.18	[.05, -.42]
TP in ms^2	1969 (2064)	2615 (2435)	2247 (2238)	507 (-1.46)	-.17	[.06, -.41]
[a]ln SDNN	3.82 (0.42)	3.98 (0.38)	3.89 (0.40)	-1.62	-0.40	[0.07, -0.87]
[a]ln rMSSD	3.59 (0.66)	3.85 (0.55)	3.70 (0.63)	-1.78	-0.42	[0.05, -0.89]
[a]ln CV	1.87 (0.32)	1.91 (0.31)	1.89 (0.31)	-0.53	-0.13	[0.34, -0.59]
[a]ln LF	6.49 (0.85)	6.73 (0.87)	6.59 (0.86)	-1.18	-0.28	[0.19, -0.75]
[a]ln HF	6.34 (1.13)	6.82 (0.91)	6.55 (1.06)	-1.95	-0.46	[0.01, -0.93]
[a]ln LF/HF	0.15 (0.64)	-0.09 (0.57)	0.05 (0.62)	1.65	0.39	[-0,08, 0.86]
[a]ln TP	7.17 (0.93)	7.52 (0.84)	7.32 (0.90)	-1.64	-0.39	[0.08, -0.86]

Notes. The last column represents mean differences between girls and boys. Depending on the data distribution, either the parametric t-test or the non-parametric U-test is reported. According to Cohen (1988), effect sizes are small ($d \geq 0.20$, $r \geq .10$), medium ($d \geq 0.50$, $r \geq .30$), or large ($d \geq 0.80$, $r \geq .50$). CI = confidence interval for d/r; CV = coefficient of variation of IBIs; HF = high frequency power; HF nu = normalized units of HF; HR = (mean) heart rate; HRV = heart rate variability; IBI = (mean) interbeat interval; LF = low frequency power; LF nu = normalized units of LF; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power.

** $p < .01$, all other values are non-significant.

[a] Comparison of means based on a t-test.

Table 17

Descriptive Statistics and Gender Differences for Self-Reported Stress Vulnerability, Stress Symptoms, and Coping Strategies as well as Internal Consistencies (Cronbach's α) of all Subscales (SSKJ 3-8; Lohaus et al., 2006)

Scale	α	Female (*n* = 41) *M* (*SD*)	Male (*n* = 31) *M* (*SD*)	Total (*N* = 72) *M* (*SD*)	*t*	*d*	[95% CI]
Stress vulnerability	.46	16.68 (2.52)	15.06 (2.48)	15.99 (2.61)	2.72**	0.65	[0.17, 1.13]
Coping strategy							
Seeking social support	.84	34.39 (7.56)	27.74 (7.92)	31.53 (8.35)	3.62***	0.86	[0.38, 1.34]
Problem-focused Coping	.90	43.39 (7.15)	42.77 (9.91)	43.13 (8.39)	0.31	0.07	[-0.39, 0.54]
Avoidant coping	.83	25.76 (6.91)	26.61 (8.95)	26.12 (7.81)	-0.46	-0.11	[0.36, -0.58]
Constructive-palliative ER	.83	29.93 (8.53)	30.87 (8.09)	30.33 (8.30)	-0.48	-0.11	[0.35, -0.58]
Destructive-anger-related ER	.86	24.83 (7.62)	23.35 (8.20)	24.19 (7.85)	0.79	0.19	[-0.28, 0.66]
Physical symptoms	.71	9.63 (2.56)	8.29 (2.55)	9.06 (2.62)	2.21*	0.53	[0.05, 1.00]
Psychological symptoms	.89	23.90 (6.81)	22.13 (5.27)	23.14 (6.22)	1.25	0.29	[-0.18, 0.75]

Notes. Scale minima and maxima are: Six to 24 points (stress vulnerability), twelve to 60 points for coping strategies (aggregated values for both situations), six to 18 points (physical symptoms), and twelve to 36 points for psychological symptoms. The last three columns represent mean differences between girls and boys. According to Cohen (1988), effect sizes are small ($d \geq 0.20$), medium ($d \geq 0.50$), or large ($d \geq 0.80$). CI = confidence interval for *d*; ER = emotion regulation.

* $p < .05$, ** $p < .01$, *** $p < .001$, all other values are non-significant.

4.3.2. Intercorrelations and Bivariate Considerations of Stress, Coping, HRV, and School Achievement

When looking at the intercorrelations of the HRV parameters (Table 18), an important aspect is worth mentioning: The parameters HF nu, LF nu, and ln LF/HF are almost perfectly correlated with each other. This is a result of the underlying mathematic equations, meaning that these parameters are mathematically redundant (although different underlying physiological mechanisms have been suggested; see Burr, 2007; Chemla et al., 2005; Heathers, 2014). In a similar vein, HR and IBI are simple transformations of each other as also indicated by their high correlation of r = -.97, p < .001 (e.g., see Sacha, 2013, 2014; Sacha, Barabach, et al., 2013). To avoid redundancies, we decided to exclude HR, HF nu and LF nu from further analyses. Therefore, remaining parameters are: IBI, ln SDNN, ln rMSSD, ln CV, ln HF, ln LF, ln LF/HF, and ln TP. Note that SNS and PNS activity is appropriately covered by these parameters (Appelhans & Luecken, 2006; Berntson et al., 1997; Cygankiewicz & Zareba, 2013; Hoyer, 2009; Shaffer et al., 2014; Stein & Kleiger, 1999; Task Force, 1996).

Table 18

Pearson Correlations (r) for HRV Parameters (N = 72)

	Parameter	1	2	3	4	5	6	7	8	9	10
1	IBI	-									
2	HR	-.97***	-								
3	ln SDNN	.68***	-.71***	-							
4	ln rMSSD	.76***	-.80***	.92***	-						
5	ln CV	.36**	-.40***	.93***	.78***	-					
6	ln HF	.71***	-.75***	.90***	.92***	.79***	-				
7	HF nu	.36**	-.40***	.29*	.53***	.18	.57***	-			
8	ln LF	.61***	-.63***	.90***	.74***	.83***	.81***	-.01	-		
9	LF nu	-.36**	.40***	-.29*	-.53***	-.18	-.57***	-1.00***	.01	-	
10	ln LF/HF	-.37**	.40***	-.30*	-.54***	-.19	-.58***	-1.00***	.00	1.00***	-
11	ln TP	.69***	-.72***	.95***	.88***	.86***	.96***	.32**	.94***	-.32**	-.32**

Notes. According to Cohen (1988), effect sizes are small ($r \geq .10$), medium ($r \geq .30$), or large ($r \geq .50$). CV = coefficient of variation of IBIs; HF = high frequency power; HF nu = normalized units of HF; HR = (mean) heart rate; HRV = heart rate variability; IBI = (mean) interbeat interval; LF = low frequency power; LF nu = normalized units of LF; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power.
* $p < .05$, ** $p < .01$, *** $p < .001$, all other values are non-significant.

The interrelations of the SSKJ 3-8 subscales (Lohaus et al., 2006) are shown in Table 19. Based on data reported by the questionnaire authors (Eschenbeck et al., 2006; Lohaus et al., 2006), the relationships found in our sample are – by and large - in line with the expectations. Exceptions are negative correlations between physical symptoms and problem-focused coping ($r = -.41$, $p < .001$) as well as between psychological symptoms and problem-focused coping ($r = -.24$, $p = .041$). Note that the lower limit of significant correlations within this sample is about $r = .23$ (two-tailed, $N = 72$, $\alpha = .05$, power = .80; G*Power; Faul et al., 2009).

Table 19

Pearson Correlations (r) within SSKJ 3-8 Scales (N = 72; Lohaus et al., 2006)

	Scale	1	2	3	4	5	6	7
1	Stress vulnerability	-						
2	Seeking social support	.34**	-					
3	Problem-focused Coping	.22	.49***	-				
4	Avoidant coping	-.19	-.20	-.36**	-			
5	Constructive-palliative ER	-.06	.05	-.03	.49***	-		
6	Destructive-anger-related ER	.17	-.08	-.30**	.37**	.33**	-	
7	Physical symptoms	.36**	.01	-.41***	.22	.02	.41***	-
8	Psychological symptoms	.35**	-.13	-.24*	.10	-.06	.42***	.64***

Notes. According to Cohen (1988), effect sizes can be considered as small ($r \geq .10$), medium ($r \geq .30$), or large ($r \geq .50$). ER = emotion regulation.
* $p < .05$, ** $p < .01$, *** $p < .001$, all other values are non-significant.

Spearman correlations between SSKJ 3-8 subscales (Lohaus et al., 2006) and GPA reveal a positive relationship between problem-focused coping and overall GPA ($r_s = .32$, $p = .007$). Furthermore, overall GPA and destructive-anger-related emotion regulation are negatively correlated ($r_s = -.23$, $p = .049$), as also between overall GPA and self-reported physical stress symptoms ($r_s = -.29$, $p = .015$). Concerning the more specific GPAs arising from mathematical and English performance of the pupils, there are also negative relationships with respect to psychological stress symptoms (mathematics GPA: $r_s = -.25$, $p = .031$; English GPA: $r_s = -.25$, $p = .032$). In contrast, correlation analysis for HRV parameters and overall GPA reveals only one significant relationship (ln LF/HF: $r_s = .28$, $p = .019$). However, the English GPA is negatively associated with IBI ($r_s = -.25$, $p = .034$), ln SDNN ($r_s = -.26$, $p = .031$), and ln rMSSD ($r_s = -.30$, $p = .012$). All correlations are shown in Table 20. Finally, stress and coping subscales are mainly unrelated to HRV indices (see Table 21).

Table 20

Spearman Correlations (r_s) for SSKJ 3-8 (Lohaus et al., 2006), GPA, and HRV (N = 72)

Variable	German GPA	Mathematics GPA	English GPA	Overall GPA
SSKJ 3-8 scale				
Stress vulnerability	.06	-.01	-.17	-.04
Seeking social support	.08	.02	.08	.08
Problem-focused Coping	.18	.05	.25*	.32**
Avoidant coping	.10	.04	-.06	-.11
Constructive-palliative ER	.24*	.18	.01	.05
Destructive-anger-related ER	.06	-.13	-.31**	-.23*
Physical symptoms	-.14	-.31**	-.27*	-.29*
Psychological symptoms	.01	-.25*	-.25*	-.19
HRV parameter				
IBI	-.13	-.25*	-.25*	-.11
ln SDNN	-.03	-.07	-.26*	-.08
ln rMSSD	-.04	-.17	-.30*	-.16
ln CV	.02	.03	-.21	-.04
ln HF	-.09	-.06	-.22	-.12
ln LF	-.04	.02	-.19	.02
ln LF/HF	.10	.13	.14	.28*
ln TP	-.08	-.02	-.21	-.06

Notes. According to Cohen (1988), effect sizes can be considered as small ($r \geq .10$), medium ($r \geq .30$), or large ($r \geq .50$). CV = coefficient of variation of IBIs; ER = emotion regulation; GPA = grade point averages; HF = high frequency power; HRV = heart rate variability; IBI = (mean) interbeat interval; LF = low frequency power; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of the mean squared differences of consecutive interbeat intervals; SDNN = standard deviation of the interbeat intervals; TP = total power.

* $p < .05$, ** $p < .01$, all other values are non-significant.

Table 21

Pearson Correlations (r) for SSKJ 3-8 Scales (Lohaus et al., 2006) and HRV Parameters (N = 72)

Variable	IBI	ln SDNN	ln rMSSD	ln CV	ln HF	ln LF	ln LF/HF	ln TP
Stress vulnerability	-.15	-.01	.02	.08	.02	-.05	-.09	-.00
Seeking social support	-.19	-.14	-.15	-.06	-.15	-.14	.07	-.14
Problem-focused Coping	.01	-.03	-.08	-.04	-.00	.03	.05	.02
Avoidant coping	.07	.20	.16	.22	.14	.18	.01	.17
Constructive-palliative ER	.10	.13	.14	.11	.12	.05	-.14	.09
Destructive-anger-related ER	.08	.11	.16	.10	.08	-.02	-.16	.03
Physical symptoms	.00	.04	.10	.06	-.00	-.07	-.09	-.03
Psychological symptoms	-.03	-.13	-.01	-.15	-.13	-.22	-.08	-.18

Notes. According to Cohen (1988), effect sizes are small ($r \geq .10$), medium ($r \geq .30$), or large ($r \geq .50$). CV = coefficient of variation of IBIs; ER = emotion regulation; HF = high frequency power; HRV = heart rate variability; IBI = (mean) interbeat interval; LF = low frequency power; LF/HF = ratio of LF and HF; ln = natural logarithm; rMSSD = square root of the mean squared differences of consecutive IBIs; SDNN = standard deviation of IBIs; TP = total power.
All correlations are non-significant.

4.3.3. Predicting Stress Symptoms and School Achievement

A multiple regression analysis for physical stress symptoms (forced entry) reveals three significant predictors: Stress vulnerability (β = .22, p = .027), problem-focused coping (β = -.25, p = .012), and self-reported psychological symptoms (β = .43, p < .001). When considering semi-partial correlations, overall GPA ($r_{a(b.c)}$ = -.15, β = -.16, p = .074) also emerges as a predictor of physical stress symptoms. Overall, predictors explain about 59 % (*adjusted* R^2 = .54) of the variance of physical stress symptoms, F(8,63) = 11.47, p < .001 (see Table 22). Stepwise regression reveals analogous results, and includes psychological symptoms at the first step (ΔR^2 = .45), problem-focused coping at step two (ΔR^2 = .07), and stress vulnerability at the last step (ΔR^2 = .04). The final stepwise model explains 56 % of the variance (52 % adjusted), F(5,66) = 16.62, p < .001. Regression coefficients are β = .46 for psychological symptoms (p < .001), β = -.35 for problem-focused coping (p < .001), and β = .23 for stress vulnerability (p = .023). Again, overall GPA missed the inclusion into the model (β = -.17, p = .063); nevertheless, there is a notable partial correlation with the outcome ($r_{ab,c}$ = -.23).

Multiple regression analyses with psychological symptoms as a criterion reveal a more complex picture. The forced entry method identifies two significant predictors, namely physical symptoms (β = .55, p < .001) and seeking for social support (β = -.27, p = .025). In addition, semi-partial correlations suggest a predictive value of stress vulnerability ($r_{a(b.c)}$ = .15, β = .18, p = .094) and destructive-anger-related emotion regulation ($r_{a(b.c)}$ = .17, β = .19, p = .061). The overall model explains about 54 % of variance (*adjusted* R^2 = .47), with F(10,61) = 7.17 and p < .001 (see Table 22). For the stepwise regression, only physical symptoms remain in the model (β = .65, p <. 001), with a variance explanation of R^2 = .42 (*adjusted* R^2 = .39). However, note that ln LF (β = -.18, p = .054, $r_{ab,c}$ = -.23), destructive-anger-related emotion regulation (β = .19, p = .062, $r_{ab,c}$ = .23), seeking social support (β = -.14, p = .167, $r_{ab,c}$ = -.17), and stress vulnerability (β = .16, p = .116, $r_{ab,c}$ = .19) reveal predictive potential, as is indicated by their partial correlations with psychological symptoms.

The overall GPA of the pupils is best predicted by their self-reported physical stress symptoms (β = -.28 and p = .094) and the use of problem-focused coping (β = .22 and p = .091), although these predictors become non-significant within the forced entry model (R^2 = .27, *adjusted* R^2 = .17), F(9,62) = 2.60, p = .013 (see Table 22). Moreover, stepwise regression identifies physical stress symptoms as the only significant predictor of overall GPA (β = -.40, p < .001), with R^2 = .18 and *adjusted* R^2 = .15. An inspection of excluded variables reveals additional predictive potential of ln LF/HF (β = .22, p = .052, $r_{ab,c}$ = .24) and problem-focused coping (β = .21, p = .079, $r_{ab,c}$ = .21).

Table 22

Multiple Regressions (Forced Entry) Predicting Pupils' Self-Reported Stress Symptoms and Overall GPA Controlled for Age and Gender (N = 72)

	Model for Physical Symptoms					Model for Psychological Symptoms					Model for Overall GPA				
Predictor	*b*	[95% CI]	*SE B*	β	*p*	*b*	[95% CI]	*SE B*	β	*p*	*b*	[95% CI]	*SE B*	β	*p*
(Constant)	10.49	[2.33, 18.66]	4.09		.013	7.51	[-16.70, 31.72]	12.11		.537	6.17	[4.40, 7.93]	0.88		< .001
Stress vulnerability	0.22	[0.03, 0.42]	0.10	.22	.027	0.44	[-0.08, 0.95]	0.26	.18	.094					
Seeking social support						-0.20	[-0.37, -0.03]	0.09	-.27	.025					
Problem-focused coping	-0.08	[-0.14, -0.02]	0.03	-.25	.012	0.10	[-0.09, 0.29]	0.09	.13	.301	0.01	[0.00, 0.03]	0.01	.22	.091
Avoidant coping	0.04	[-0.02, 0.10]	0.03	.12	.209						0.00	[-0.01, 0.02]	0.01	.03	.804
Destructive-anger-related ER	0.00	[-0.06, 0.07]	0.03	.01	.908	0.15	[-0.01, 0.30]	0.08	.19	.061	-0.01	[-0.02, 0.01]	0.01	-.07	.593
Physical symptoms						1.31	[0.75, 1.87]	0.28	.55	< .001	-0.05	[-0.12, .0.01]	0.03	-.28	.083
Psychological symptoms	0.18	[0.10, 0.26]	0.04	.43	< .001						0.00	[-0.02, 0.03]	0.01	.04	.771
Overall GPA	-0.84	[-1.77, 0.08]	0.46	-.16	.074	0.00	[-2.52, 2.52]	1.26	.00	.999					
ln HF						-0.36	[-2.24, 1.53]	0.94	-.06	.707	-0.03	[-0.16, 0.11]	0.07	-.06	.676
ln LF						-1.15	[-3.38, 1.08]	1.11	-.16	.306					
ln LF/HF											0.15	[-0.08, 0.38]	0.11	.18	.198

Notes. Model for physical symptoms: R^2 = .59; R_a^2 = .54 (p < .001). Model for psychological symptoms: R^2 = .54; R_a^2 = .47 (p < .001). Model for overall GPA: R^2 = .27; R_a^2 = .17 (p = .013). Following the recommendations of Cohen (1988), $R^2 \geq .02$ is a small, $R^2 \geq .13$ a medium, and $R^2 \geq .26$ a large effect. Empty cells are attributable to the previous exclusion of predictors not meaningfully correlating with the criterion. *b* = unstandardized regression coefficient; β = standardized regression coefficient; CI = confidence interval for *b*; ER = emotion regulation; GPA = grade point average; HF = high frequency; LF = low frequency; LF/HF = ratio of LF and HF; ln = natural logarithm; R^2 = coefficient of determination; R_a^2 = adjusted R^2.

Based on the regression results, we provide multiple regression models (forced entry) for physical stress symptoms, psychological stress symptoms, and overall GPA. Therefore, we select those predictors, which (a) contribute significantly to variance explanation within the previous models, (b) show predictive potential as indicated by their standardized regression coefficients or effect sizes (see Table 23). We assume that the latter group of variables did not reach significance simply because of the available sample size.

The most important variable predicting physical symptoms are psychological stress symptoms ($\beta = .44$, $p < .001$, $r_{a(b.c)} = .38$), followed by problem-focused coping ($\beta = -.29$, $p = .003$, $r_{a(b.c)} = -.25$), stress vulnerability ($\beta = .21$, $p = .035$, $r_{a(b.c)} = .17$), and the overall GPA ($\beta = -.17$, $p = .063$, $r_{a(b.c)} = -.15$). The model is significant, with $F(6,65) = 14.98$ ($p < .001$), and accounts for 58 % of the variance (54 % adjusted). In turn, psychological stress symptoms are best predicted by physical symptoms ($\beta = .50$, $p < .001$, $r_{a(b.c)} = .42$), stress vulnerability ($\beta = .22$, $p = .033$, $r_{a(b.c)} = .19$), coping based on social support ($\beta = -.21$, $p = .041$, $r_{a(b.c)} = -.18$), the HRV parameter ln LF ($\beta = -.20$, $p = .025$, $r_{a(b.c)} = -.20$), and destructive-anger-related emotion regulation ($\beta = .17$, $p = .085$, $r_{a(b.c)} = .15$). With 53 % (48 % adjusted), this model explains a large amount of variance, $F(7,64) = 10.34$, $p < .001$. Finally, school achievement in terms of overall GPA is predicted by self-reported physical stress symptoms ($\beta = -.27$, $p = .031$, $r_{a(b.c)} = -.23$), the LF/HF ratio ($\beta = .22$, $p = .043$, $r_{a(b.c)} = .22$), and problem-focused coping ($\beta = .22$, $p = .065$, $r_{a(b.c)} = .20$). 27 % of variance are explained (21 % adjusted), $F(5,66) = 4.82$, $p < .001$, while achieved power is 98 % ($\alpha = .05$; G*Power; Faul et al., 2009).

Table 23

Final Multiple Regressions (Forced Entry) Predicting Pupils' Self-Reported Stress Symptoms and GPA Controlled for Age and Gender (N = 72)

	Model for Physical Symptoms					Model for Psychological Symptoms					Model for Overall GPA				
Predictor	*b*	[95% CI]	*SE B*	β	*p*	*b*	[95% CI]	*SE B*	β	*p*	*b*	[95% CI]	*SE B*	β	*p*
(Constant)	12.21	[4.52, 19.90]	3.85		.002	9.49	[-8.01, 27.00]	8.76		.283	5.93	[4.48, 7.37]	0.72		< .001
Stress vulnerability	0.21	[0.02, 0.40]	0.10	.21	.035	0.52	[0.04, 0.99]	0.24	.22	.033					
Seeking social support						-0.15	[-0.30, -0.01]	0.07	-.21	.041					
Problem-focused coping	-0.09	[-0.15, -0.03]	0.03	-.29	.003						0.01	[0.00, 0.03]	0.01	.22	.065
Destructive-anger-related ER						0.13	[-0.02, 0.28]	0.08	.17	.085					
Physical Symptoms						1.17	[0.69, 1.66]	0.24	.50	< .001	-0.05	[-0.10, -0.01]	0.02	-.27	.031
Psychological symptoms	0.19	[0.11, 0.26]	0.04	.44	< .001										
Overall GPA	-0.87	[-1.79, 0.05]	0.46	-.17	.063										
ln LF						-1.44	[-2.69, -0.19]	0.63	-.20	.025					
ln LF/HF											0.18	[0.01, 0.36]	0.09	.22	.043

Notes. Model for physical symptoms: R^2 = .58; R_a^2 = .54 (p < .001). Model for psychological symptoms: R^2 = .53; R_a^2 = .48 (p < .001). Model for overall GPA: R^2 = .27; R_a^2 = .21 (p < .001). Following the recommendations of Cohen (1988), $R^2 \geq .02$ can be considered as small, $R^2 \geq .13$ as medium, and $R^2 \geq .26$ as large effect. *b* = unstandardized regression coefficient; β = standardized regression coefficient; CI = confidence interval for *b*; ER = emotion regulation; GPA = grade point average; LF = low frequency power; LF/HF = ratio of LF and HF; ln = natural logarithm; R^2 = coefficient of determination; R_a^2 = adjusted R^2.

4.4. Discussion

We investigated the relationships between stress, coping, HRV, and school achievement within an educational context considering several hypotheses:

(1) School achievement is impaired by self-reported stress vulnerability and stress symptoms (e.g., as indicated by Cunningham et al., 2002; Gillock & Reyes, 1999; D. S. Kaplan et al., 2005; Levitt et al., 1994; Stewart et al., 1999).
(2) Emotion regulating and avoidant coping strategies are negatively related to school achievement, which on the other hand benefits from problem-focused coping (e.g., Brdar et al., 2006; Causey & Dubow, 1992; Compas et al., 2001; MacCann et al., 2011; Weis et al., 2013; Windle & Windle, 1996).
(3) Subjective stress is associated with increasing SNS activity and/or decreasing PNS activity (e.g., Berntson & Cacioppo, 2004; Dishman et al., 2000; Lucini et al., 2005; Michels, Sioen, et al., 2013; Porges, 1995a).
(4) Passive coping is negatively associated with vagal tone (O'Connor et al., 2002), while active coping styles (i.e., problem-focussed, support seeking) are positively related to vagal tone (Fabes & Eisenberg, 1997).
(5) School performance benefits from a higher vagal tone (Hansen et al., 2003; Suess et al., 1994; Thayer et al., 2009).
(6) Finally, subjective physical and psychological stress symptoms should be related to pupils' stress vulnerability and some of the reported coping strategies (Beck et al., 2016; Compas et al., 2001; Hoffman, Levy-Shiff, Sohlberg, & Zarizki, 1992; Lohaus et al., 2006; Lohaus, Fridrici, & Maass, 2009; Seiffge-Krenke & Klessinger, 2000; Windle & Windle, 1996).

In line with these hypotheses, our results confirm that self-reported physical stress symptoms are negatively related to pupils' school achievement, as is evident vis-à-vis correlative analyses and regression models. Furthermore, correlations between psychological stress symptoms on one hand and English and mathematics GPA on the other hand reveal the same patterns (i.e., small effect sizes; J. Cohen, 1988). Based on our data, when it comes to school achievement, we see that problem-focused coping is clearly the most important coping strategy: Pupils engaging in problem-focused coping achieve better grades. In contrast, destructive-anger-related emotion regulation is negatively correlated with overall GPA; however, this relationship is not validated by regression analyses. The same is true for avoidant coping. Contrary to our expectation, stress vulnerability does not turn out as a relevant predictor of overall GPA.

The HRV patterns which are typically expected under stress conditions, such as enhanced SNS and reduced PNS activity or higher values of LF/HF, are not confirmed by our data. Neither the correlative analyses nor the regressions provide such evidence. Conversely, increasing values of ln LF are accompanied by lower scores of psychological stress symptoms. One reason might be that the low frequency power (represented by the LF-component) is not only attributable to the activity of the SNS (e.g., Berntson et al., 1997; Eckberg, 1997; Laborde et al., 2017; Pumprla et al., 2002; Shaffer et al., 2014), which complicates the interpretation of HRV patterns considerably. Furthermore, studies reporting the mentioned stress patterns often used different methods for inducing stress as well as highly diverse measurements of human stress (see also Berntson & Cacioppo, 2004). For example, Delaney and Brodie (2000) used a Stroop test (see Stroop, 1935) and arithmetic tasks for inducing psychological stress. HRV changes of the experimental group are characterized by higher values of LF and LF/HF and lower values of HF (in terms of normalized units). As already mentioned: From a mathematical perspective, these parameters are redundant and do not represent different aspects of autonomic modulation (see Burr, 2007; Chemla et al., 2005; Heathers, 2014). Hence, increasing LF nu must always be accompanied by decreasing HF nu and increasing LF/HF. Another example is a systematic review by Jarczok and others (2013) revealing an inverse association between occupational stress and vagal HRV parameters as reported by ten of 19 reviewed studies. This also means that this association is not confirmed by nine of 19 studies. Thus, in accordance with other authors we assume that it is an oversimplification of the available data to postulate a general effect of stress on autonomic modulation (or vice versa; Berntson & Cacioppo, 2004), as these relationships strongly depend on the kind of stress and the applied methodological procedure. Moreover, as far as we know, there are only a few studies investigating the relationships between self-reported stress and HRV (especially in children). Furthermore, potential publication biases or partial result reporting might contribute to the existing literature (see Tak et al., 2009; Zahn et al., 2016). In a similar vein, the assumption that vagal tone (represented by rMSSD and HF-related parameters) correlates with both passive and more active coping strategies is not confirmed by our data.

Note that LF/HF is the only significant HRV parameter predicting school performance. This is contra-intuitive, as previous research has suggested a positive influence of vagal tone on cognitive performance (see above, hypothesis 5). With respect to the previous remark that the LF power spectrum represents more than only sympathetic activity (i.e., also PNS and baroreceptor activity), the description of LF/HF as an indicator of sympathovagal balance (as proposed by Malliani et al., 1991; Pagani et al., 1984, 1986) is outdated for several reasons (for a more complex discussion of this point, see Berntson et al., 1997; Billman, 2013; Eckberg, 1997; Heathers, 2014; Shaffer et al., 2014). Therefore, a sound interpretation of this statistic is very difficult and, to date, impossible. Also note that there are studies questioning the relation between HRV (at rest) and cognitive/academic performance (e.g., Becker et al., 2012; K. S. Kim & Nam, 2010).

4.4.1. Predicting Stress Symptoms and School Achievement

Overall, our results suggest that self-reported physical stress symptoms, such as headaches, nausea, or loss of appetite, are best predicted by psychological stress symptoms (anger, sadness, and anxiety), followed by problem-focused coping, stress vulnerability, and overall GPA. These data patterns are in line with findings on the relationship between stress and school achievement (Cunningham et al., 2002; Gillock & Reyes, 1999; D. S. Kaplan et al., 2005; Levitt et al., 1994; Stewart et al., 1999), and also with findings reported by the questionnaire authors (Lohaus et al., 2006, 2009).

A new finding for our sample is that the extent of physical symptoms is predicted by use of problem-focussed coping strategies (i.e., more frequent problem-focussed coping decreases the physical stress level; see also Beck et al., 2016). From a conceptual point of view, this effect is quite plausible (for a summary, see Compas et al., 2001).

In a similar vein, psychological stress symptoms are best predicted by physical symptoms and stress vulnerability. Likewise, searching for social support reduces the perception of psychological symptoms, whereas destructive-anger-related emotion regulation is associated with their increase. Finally, overall GPA is predicted by subjective physical stress symptoms (higher stress symptoms predicts lower GPAs), problem-focused coping (higher values predicting higher GPAs), and the LF/HF-ratio (larger ratios predicting higher GPAs).

To summarize, physical and psychological symptoms are best predicted by the SSKJ 3-8 subscales (Lohaus et al., 2006). The overall GPA is also mainly predicted by subscales of the SSKJ 3-8. HRV parameters do not contribute to the prediction of these variables as expected.

4.4.2. Gender Differences

Female pupils are characterized by significantly higher heart rates as compared to male pupils (medium effect size; J. Cohen, 1988). This finding is in line with the majority of studies (Brunetto, Roseguini, Silva, Hirai, & Guedes, 2005; Gutin et al., 2005; Jarrin et al., 2015; Koenig & Thayer, 2016; Michels, Sioen, et al., 2013; Reed, Warburton, Whitney, & McKay, 2006). All other HRV differences are not significant.

Furthermore, girls report a higher degree of stress vulnerability, are more likely to engage in seeking social support, and experience physical stress symptoms more often (these are medium to large effects; J. Cohen, 1988). These differences are also supported by the existing literature (Beck et al., 2016; Eschenbeck, 2010; Eschenbeck et al., 2007; Hampel & Petermann, 2006; Lohaus et al., 2004). Although existing evidence suggests better GPAs for language subjects in favour of girls (e.g., see Rohrmann, 2007; Weis et al., 2013), we did not obtain any sex differences with respect to GPAs.

4.4.3. Strengths and Limitations

To our knowledge so far, this is the first study analysing interdependencies between stress, coping, HRV, and school performance of pupils. We provided a first attempt to include these constructs into a comprehensive statistical model. Furthermore, we took great care to keep the study conditions as constant as possible and to comply with present standards and recommendations for HRV measurements (Laborde et al., 2017; Quintana et al., 2016; Task Force, 1996). The use of a standardized, reliable, and validated questionnaire for assessing pupils perceived stress and coping strategies (SSKJ 3-8; Lohaus et al., 2006) should also be highlighted, although the pros and cons of self-reports are well-known (e.g., see McDonald, 2008). Thus, it should be underlined that the present study investigated subjective perceived stress and coping strategies.

Although we tried to control as many of the factors influencing autonomic modulation as possible, an entire control of all potential influences is almost impossible (e.g., circadian influences; Bilan et al., 2005; Boudreau et al., 2012; Guo & Stein, 2002; Huikuri et al., 1990). Comprehensive overviews of influences are described elsewhere (e.g., Fatisson et al., 2016; Valentini & Parati, 2009). Despite the strong influence of respiration on HRV indices (e.g., see Allen et al., 2007; Appelhans & Luecken, 2006; Berntson et al., 1993; Eller-Berndl, 2015; Shaffer et al., 2014), respiration has not been recorded within the present study. As there is an on-going discussion on the handling of respiration (e.g., Allen et al., 2007; Denver et al., 2007; Grossman et al., 1991; Grossman & Taylor, 2007; Hirsch & Bishop, 1981; Ritz, 2009), we followed the position that respiration has not to be recorded under resting conditions und during spontaneous breathing (e.g., see Allen et al., 2007; Denver et al., 2007; Laborde et al., 2017; Quintana et al., 2016). More recent studies on HRV of children and adolescents emphasizing an additional recommendation, which is worth mentioning at this point: Since respiratory rates of children decrease with age, the frequency bands should be adapted when examining HRV of children (LF: 0.04 to 0.24 Hz, HF: 0.24 to 1.04 Hz; Fleming et al., 2011; Koenig et al., 2016; Quintana et al., 2016). As the use of the “standard frequency bands” is especially problematic when investigating infants and young children as well as for technical reasons, this recommendation was not taken not into account.

The extent to which school grades (i.e., GPAs) are appropriate indicators of school performance or cognitive performance can be controversially debated. Of course, many other variables beyond cognitive performance might be responsible for pupils’ GPAs (e.g., effort, social support, sympathy, illness). In planning and conceptualizing the present study, we decided to forego of additional performance tasks/tests for economic reasons. Hence, our main interest has been focused to a more general outcome of school performance, resulting from the whole school year.

Additionally, the cross-sectional design of the present study is accompanied by the difficulty that the direction of relationships is not clear. Therefore, we cannot make statements about cause-effect relationships, although the literature provides some evidence (as already discussed). Thus, the proposed prediction models are of statistical nature.

However, for organizational reasons, the assessment of stress and coping strategies within the present study took place on average about ten days before the individual HRV measurements were carried out. Note that HRV measurements are subject to comparatively low test-retest reliability (see Chapter III as well as Cipryan & Litschmannova, 2013, 2014; Dietrich et al., 2010; Maestri et al., 2009; Pinna et al., 2007) and to a large number of current influence factors (see Fatisson et al., 2016). In this regard, it can be concluded that HRV parameters reflecting a large amount of situational influences and should not be considered as trait-like characteristic of human physiology (see also Bertsch et al., 2012), although the polyvagal theory (Porges, 1995b, 2001, 2007) and the model of neurovisceral integration (Thayer & Lane, 2000, 2009) indicate a partly dispositional nature of HRV. Therefore, the time interval between stress assessment and HRV measurements might had influenced our results. Nevertheless, as stress vulnerability and coping strategies seem to be – at least medium-term – stable over time (Lohaus et al., 2006), we assume that the temporal lag should not have overly affected these two constructs.

Finally, the investigated constructs had been assessed by different methods. That is, stress and coping is measured by a self-assessment questionnaire, HRV by ECG recordings, and school achievement by a general performance indicator. As debated since the influential work of Campbell and Fiske (1959), relationships between psychological constructs depend on both the constructs themselves and the methods used for assessing these constructs (for a detailed discussion, see Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). Accordingly, the associations between stress vulnerability, coping, and stress symptoms are possibly also a result of the identical measurement method. The opposite is true for the non-existing, contrary, or existing relationships between stress (including coping), HRV, and school achievement.

4.4.4. Conclusion and Further Research

Our results suggest that the GPA of pupils is, at least partly, related to their experienced stress symptoms and their tendency to engage in problem-focused coping. In turn, the stress symptoms themselves are, inter alia, dependent on applied coping strategies and overall stress vulnerability.

Most importantly, measurements of HRV do not allow for a prediction of stress or school achievement. Therefore, our data question often reported HRV stress patterns, at least in terms of subjective, self-reported stress levels among high school students.

Finally, our results highlight important approaches when it comes to supporting pupils. Because school stress, composed of several facets, such as examination anxiety, teachers' and parents' expectations, or peer conflicts, can hardly be avoided, pupils should be particularly encouraged to acquire and use adaptive coping strategies. Further research on this topic should include longitudinal studies and larger sample sizes to assess indicators of stress adequately.

Chapter V

5. Summary, Overall Discussion, and Outlook

Very briefly, how can I explain the basic concept of heart rate variability (HRV)? In my opinion, Shaffer and colleagues (2014) have done an excellent job within the following lines: "[…] we now know that the normal resting sinus rhythm of the heart is highly irregular during steady-state conditions rather than being monotonously regular, which was the widespread notion for many years. *A healthy heart is not a metronome*" (p. 5). This discovery, which is not a new finding at all (see Chapter I), was my "scientific point of departure" about five years ago. Since then, I tried to acquire a lot of knowledge, have dealt with methodological issues, and ways of applying HRV measurements within a psychological context. In what follows, I will (a) summarize my findings, (b) highlight my own contributions to the current state of research, (c) provide an insight into latest developments in HRV research. (d) I will conclude this chapter by summarizing the most important lessons I have learned so far.

5.1. Summary and Contributions to Existing Literature

Within the introduction section of the present monograph (Chapter I), I outlined some basics concerning HRV, with a particular focus on short-term measurements. In this vein, two points are worth mentioning: First, my introduction is a compressed illustration of the essential physiological and psychological knowledge. Second, and this is closely connected to the first remark, it is a challenging task to oversee and integrate the enormous body of literature on HRV. For this purpose, I would like to recommend the interested reader my favourite articles in this regard: Due to its special attention on the interplay between psychological (emotional) and physiological processes, the paper by Appelhans and Luecken (2006) is highly advisable. In addition, to familiarize with physiological underpinnings and theories of HRV, the review by

Shaffer and co-workers (2014) is a clear recommendation. Finally, an impressive overview of the multitude of factors with well-known influences on autonomic modulation is provided by Fatisson and others (2016).

The main focus of Chapter II has been the identification of current methodological standards and their implementation within empirical practice. The results of our systematic review point to a considerable extent of methodological diversity. This diversity can not only be attributed to some degrees of freedom within existing guidelines (Task Force, 1996). Above all, the characteristics of HRV data acquisition are quite heterogeneous. This is especially true for one of the most important influences on HRV measurements – i.e., subjects' respiration. On one hand, the majority of reviewed articles provides no specific information in this regard. On the downside, it became evident that respiratory influences are treated in various, completely different ways. This ambivalence is also reflected by the existing debate on this topic (see Allen et al., 2007; Berntson et al., 1997; Denver et al., 2007; Grossman et al., 1991; Grossman & Taylor, 2007; Laborde et al., 2017; Quintana & Heathers, 2014; Ritz, 2009). To date, there is no generally accepted best practice when it comes to the influence of respiration on HRV. To my knowledge, the most recent recommendation for HRV measurements under conditions of rest includes the instruction to breathe as naturally as possible, plus a note of caution: Respiration rates should lie inside the high frequency range (i.e., nine to 24 cycles per minute; Laborde et al., 2017; Thayer, Loerbroks, & Sternberg, 2011).

Moreover, with respect to the analysis interval as a basis for computing HRV parameters, we identified a large range of applied intervals. Given the dependence of HRV parameters on the length of the analysed interval (Sammito & Böckelmann, 2015; Task Force, 1996) we recommend, in line with existing standards, the use of an artefact-free five-minute interval (Allen et al., 2007; de Vries, 2013; Laborde et al., 2017; Task Force, 1996). At the same time, this recommendation impedes the application of promising geometrical and nonlinear techniques, as those often need analysis intervals of longer durations (Hoshi et al., 2013; Molina–Picó et al., 2013; Sammito et al., 2015; Task Force, 1996). Therefore, it might be a valuable consideration to expand the standardized analysis interval for short-term measurements of HRV to 20 minutes (see also de Vries, 2013).

A final critical note within Chapter II has addressed the current practices concerning the way in which results are reported. Although potential reasons for non-reporting of common HRV indices have already been discussed, I would like to repeat the importance of reporting (at best) all calculated HRV parameters. If this is not possible within the manuscript, researchers are well-advised to use either an appendix or online data repositories. Note that this recommendation is in line with most current guidelines (details are outlined below; Laborde et al., 2017; Quintana et al., 2016).

In my opinion, our systematic review is a valuable contribution to the existing literature. First, there is no other publication addressing the methodological diversity in this field in such a comprehensive way. Second, I believe that our checklist, based on current empirical evidence, will be of great support to psychologists planning or conducting research on HRV.

The longitudinal data analysed in Chapter III queries the usability of HRV parameters when it comes to determining intra-individual changes (e.g., by means of pre- and post-measurements before and after any kind of treatment; Maestri et al., 2009; Pinna et al., 2007). Therefore, the trait-like characteristic of individual HRV values (as suggested by dominating theories; Porges, 1995b, 2001, 2007, Thayer & Lane, 2000, 2009) might have been overestimated. Interestingly, neither participants' posture nor the temporal interval between repeated measurements affects reliability indices of HRV parameters systematically. Thus, the comparatively low relative and absolute reliability values for most HRV parameters inevitably lead to the conclusion that the regulation of human heartbeat is very sensitive to a variety of (controllable and uncontrollable) influences (e.g., see Cipryan & Litschmannova, 2013, 2014; Fatisson et al., 2016; Pinna et al., 2007; Valentini & Parati, 2009; Voss et al., 2015). When designing and implementing intervention studies, as many as possible of these factors should be taken into account. Moreover, large samples are needed for the reliable detection of real changes across time. Such sample size estimations, taking the reliability of HRV parameters into account, have already been provided (see Cipryan & Litschmannova, 2013, 2014; Dietrich et al., 2010; Hallman et al., 2015; Maestri et al., 2009; Pinna et al., 2007).

I have outlined some limitations of this study, especially with respect to the external validity of results and our randomization of the posture sequence. Nevertheless, I am convinced that this longitudinal study is an important contribution to HRV research, as it is quite common to use HRV measurements as an indicator of treatment effects on individual and/or group level (e.g., Aubert, Verheyden, Beckers, Tack, & Vandenberghe, 2009; Bär et al., 2004; Beresnevaitė et al., 2016; Bidwell, Yazel, Davin, Fairchild, & Kanaley, 2012; Blumenthal et al., 2005; Hallman et al., 2015; Hansen, Kvale, Stubhaug, & Thayer, 2013). In this light, the vulnerability of HRV measurements with respect to situational variables (and thus the low test-retest reliability) implies that such an application is to be viewed with caution. In addition, previous studies have investigated rather short time intervals between test and retest, and have typically implemented only two measurement sessions (e.g., Cipryan & Litschmannova, 2014; Maestri et al., 2009; Pinna et al., 2007). However, since (psychological) treatments often require more time, the consideration of HRV reliability over a time window of one year (and with a total of five measurements per subject during that time-course) provides an important extension of the current state of research.

The last study within this monograph (Chapter IV) has dealt with the relationships between self-reported stress, coping, HRV, and school achievement. Our results underpin the importance of the acquisition of constructive coping behavior within an educational context. Such coping strategies help to reduce stress symptoms, and fewer stress symptoms help to improve pupils' school performance. The expected associations between HRV and stress/coping (e.g., Berntson & Cacioppo, 2004; Dishman et al., 2000; Fabes & Eisenberg, 1997; Lucini et al., 2005; Michels, Sioen, et al., 2013; O'Connor et al., 2002; Porges, 1995a) as well as between vagal tone and cognitive performance (e.g., Hansen et al., 2003; Suess et al., 1994; Thayer et al., 2009) have not been supported by our data. The temporal distance between stress assessments and HRV measurements might be one explanation for this pattern, as the autonomic nervous system seems to be very sensitive to situational influences (e.g., Fatisson et al., 2016; Pinna et al., 2007). On the downside, individual stress vulnerability and coping strategies are likely to be stable across time (at least medium-term; Lohaus et al., 2006). Moreover, there are some clues pointing to a publication bias within HRV research (see Tak et al., 2009; Zahn et al., 2016), exacerbating the development of adequate hypotheses about the "real" relationships between these constructs.

The substantial contributions of this study to existing literature arise from the unique combination of stress, coping, physiological stress markers, and indicators of school achievement within an educational setting. In addition, we closely adhered to existing standards and guidelines for recording and reporting HRV measurements (Laborde et al., 2017; Quintana et al., 2016; Task Force, 1996), paired with the use of a standardized questionnaire (SSKJ 3-8; Lohaus et al., 2006). Our analyses, allowing for an integration of these constructs into more complex statistical models, provide also an important extension of the current state of research.

5.2. Recent Developments in HRV Research and Forthcoming Challenges

Two studies are worth-mentioning as they are closely related to Chapter II and III: After completing our systematic review, we noticed some improvement concerning new and updated recommendations for HRV measurements. Quintana and associates (2016) recently provided well-applicable reporting guidelines for HRV studies. These recommendations are largely in line with our checklist (Figure 8). Inter alia, the authors suggest a clear indication of participant characteristics (such as age, gender, luxury food consumption, physical activity) in combination with well justified inclusion and exclusion criteria. Furthermore, researchers should clearly report their procedure in collecting HRV data, with special attention on technical details (hardware and software), length of the analysed interval, and conditions of data acquisition. After recording, post processing of interbeat intervals (IBI) should be carefully indicated (e.g., treatment of artefacts). Finally, researchers are asked to illustrate their methods for HRV parameter calculation (e.g., type of spectral analysis, cut-off values for frequency bands) as well as the interpretation of these parameters.

A more comprehensive collection of recommendations has been most recently provided by Laborde and others (2017). Besides reporting guidelines, the authors emphasize the requirement of a well-considered study design, including sample size estimations, attention to influence factors, and necessary HRV parameters. Moreover, they discuss recording standards with respect to current progress (e.g., hardware, interval length, respiratory issues). Eventually, state of the art recommendations concerning data editing, data analyses, and result reporting are given.

Note that both guidelines are the result of recent findings on short-term HRV. Thus, in contrast to our checklist, they do not additionally arise from a systematic analysis of the current methodological status quo. Nevertheless, both publications are a clear confirmation of our conclusions.

In sum, both articles are examples for what I would call a “step in the right direction”. To continue the linguistic phrase, HRV research might be one step closer on the generation of standard values for short-term HRV measurements, which are highly desirable and badly needed for individual diagnostics (above all, see de Vries, 2013; Nunan et al., 2010). However, I ask myself whether standard values represent a realistic objective at all. As illustrated in Chapter II and III, the influences on individual HRV and their potential interactions present a challenging situation (see Fatisson et al., 2016; Valentini & Parati, 2009). So far as I know, potential norm values have to be necessarily very specific taking at least age, gender, health status, circadian dependences, emotional states, used hardware (e.g., ECG and sampling rate), applied spectral analysis method, and respiratory influences into account. This list is far from being exhaustive, but illustrates quite quickly the enormous number of combination possibilities and therefore the needed spectrum of standard values.

5.3. What Remains at the End of the Day?

Maybe the reader has got the impression that this work represents a quite critical analysis of HRV research. Indeed, this is the case, although this had not been my goal when I started my dissertation project. Rather, criticism has emerged as a result of my efforts to understand HRV as well as possible. My impression now is that critical consideration of the current state of HRV research is needed to move forward. And there can be no doubt that continuing research on this topic is worthwhile and urgently needed.

Finally, I would like to conclude by presenting my most important lessons learned. These relate to both scientific research in general and HRV research in particular.

5.3.1. Lessons I Have Learned So Far

Lesson I:	Multidisciplinary teams (ideally physicians, physiologists, psychologists, mathematicians, computer scientists) are essential to a comprehensive understanding of HRV.
Lesson II:	An extensive literature review necessarily requires a detailed planning phase. The subsequent collection of variables that have not been considered in my planning phase has been associated with enormous additional effort (and frustration).
Lesson III:	The standardization of experimental procedures is of particular importance for HRV studies.
Lesson IV:	Sometimes processes and relationships are much more complex as they appear at first glance. This is especially true for human physiology.
Lesson V:	HRV should be seen as indicator of a highly sensitive and rapidly changing system.
Lesson VI:	With respect to detailed reporting of methodological procedures and results, online data repositories provide a great solution to overcome limitations in terms of manuscript lengths.
Lesson VII:	Although reliable norm values are desirable from a psychological and clinical point of view, they might be an unreachable goal for short-term HRV measurements.
Lesson VIII:	If you get stuck at one point, do not be too proud to ask for help.
Lesson IX:	Setbacks and obstacles are part of the scientific process - do not be discouraged.
Lesson X:	Most importantly: Despite all scientific ambitions and enthusiasm, do not neglect the really relevant things in life.

6. References

Abhishekh, H. A., Nisarga, P., Kisan, R., Meghana, A., Chandran, S., Trichur Raju, & Sathyaprabha, T. N. (2013). Influence of age and gender on autonomic regulation of heart. *Journal of Clinical Monitoring and Computing*, *27*(3), 259–264. https://doi.org/10.1007/s10877-012-9424-3

Aboussafy, D., Campbell, T. S., Lavoie, K., Aboud, F. E., & Ditto, B. (2005). Airflow and autonomic responses to stress and relaxation in asthma: The impact of stressor type. *International Journal of Psychophysiology*, *57*(3), 195–201. https://doi.org/10.1016/j.ijpsycho.2005.02.004

Abrams, D. A., Bhatara, A., Ryali, S., Balaban, E., Levitin, D. J., & Menon, V. (2011). Decoding temporal structure in music and speech relies on shared brain resources but elicits different fine-scale spatial patterns. *Cerebral Cortex*, *21*(7), 1507–1518. https://doi.org/10.1093/cercor/bhq198

Acharya, U. R., Faust, O., Sree, V., Swapna, G., Martis, R. J., Kadri, N. A., & Suri, J. S. (2014). Linear and nonlinear analysis of normal and CAD-affected heart rate signals. *Computer Methods and Programs in Biomedicine*, *113*(1), 55–68. https://doi.org/10.1016/j.cmpb.2013.08.017

Acharya, U. R., Joseph, K. P., Kannathal, N., Lim, C. M., & Suri, J. S. (2006). Heart rate variability: a review. *Medical & Biological Engineering & Computing*, *44*(12), 1031–1051. https://doi.org/10.1007/s11517-006-0119-0

Acharya, U. R., Kannathal, N., Lee, M. H., & Leong, M. Y. (2005). Study of heart rate variability signals at sitting and lying postures. *Journal of Bodywork and Movement Therapies*, *9*(2), 134–141. https://doi.org/10.1016/j.jbmt.2004.04.001

Agelink, M. W., Malessa, R., Baumann, B., Majewski, T., Akila, F., Zeit, T., & Ziegler, D. (2001). Standardized tests of heart rate variability: Normal ranges obtained from 309 healthy humans, and effects of age, gender, and heart rate. *Clinical Autonomic Research*, *11*(2), 99–108. https://doi.org/10.1007/BF02322053

Akselrod, S., Gordon, D., Ubel, F., Shannon, D., Berger, A., & Cohen, R. (1981). Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control. *Science*, *213*(4504), 220–222. https://doi.org/10.1126/science.6166045

Allen, J. J. B., Chambers, A. S., & Towers, D. N. (2007). The many metrics of cardiac chronotropy: A pragmatic primer and a brief comparison of metrics. *Biological Psychology*, *74*(2), 243–262. https://doi.org/10.1016/j.biopsycho.2006.08.005

Almeida-Santos, M. A., Barreto-Filho, J. A., Oliveira, J. L. M., Reis, F. P., da Cunha Oliveira, C. C., & Sousa, A. C. S. (2016). Aging, heart rate variability and patterns of autonomic regulation of the heart. *Archives of Gerontology and Geriatrics*, *63*, 1–8. https://doi.org/10.1016/j.archger.2015.11.011

American Psychological Association. (2010). *Publication Manual of the American Psychological Association* (6th ed.). Washington, DC: American Psychological Association.

Antelmi, I., De Paula, R. S., Shinzato, A. R., Peres, C. A., Mansur, A. J., & Grupi, C. J. (2004). Influence of age, gender, body mass index, and functional capacity on heart rate variability in a cohort of subjects without heart disease. *The American Journal of Cardiology*, *93*(3), 381–385. https://doi.org/10.1016/j.amjcard.2003.09.065

Appelhans, B. M., & Luecken, L. J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology*, *10*(3), 229–240. https://doi.org/10.1037/1089-2680.10.3.229

Aronson, D., & Burger, A. J. (2001). Effect of beta-blockade on heart rate variability in decompensated heart failure. *International Journal of Cardiology*, *79*(1), 31–39. https://doi.org/10.1016/S0167-5273(01)00401-6

Atkinson, G., & Nevill, A. (1998). Statistical methods for assssing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, *26*(4), 217–238. https://doi.org/10.2165/00007256-199826040-00002

Aubert, A. E., Verheyden, B., Beckers, F., Tack, J., & Vandenberghe, J. (2009). Cardiac autonomic regulation under hypnosis assessed by heart rate variability: Spectral analysis and fractal complexity. *Neuropsychobiology*, *60*(2), 104–112. https://doi.org/10.1159/000239686

Axelrod, S., Lishner, M., Oz, O., Bernheim, J., & Ravid, M. (1987). Spectral snalysis of fluctuations in heart rate: An objective evaluation of autonomic nervous control in chronic renal failure. *Nephron*, *45*(3), 202–206. https://doi.org/10.1159/000184117

Baek, H. J., Cho, C.-H., Cho, J., & Woo, J.-M. (2015). Reliability of ultra-short-term analysis as a surrogate of standard 5-min analysis of heart rate variability. *Telemedicine and E-Health*, *21*(5), 404–414. https://doi.org/10.1089/tmj.2014.0104

Bär, K. J., Boettger, M. K., Andrich, J., Epplen, J. T., Fischer, F., Cordes, J., … Agelink, M. W. (2008). Cardiovagal modulation upon postural change is altered in Huntingtons disease. *European Journal of Neurology*, *15*(8), 869–871. https://doi.org/10.1111/j.1468-1331.2008.02173.x

Bär, K. J., Greiner, W., Jochum, T., Friedrich, M., Wagner, G., & Sauer, H. (2004). The influence of major depression and its treatment on heart rate variability and pupillary light reflex parameters. *Journal of Affective Disorders*, *82*(2), 245–252. https://doi.org/10.1016/j.jad.2003.12.016

Baumgartner, T. A. (1989). Norm-referenced measurement: Reliability. In M. J. Safrit & T. M. Wood (Eds.), *Measurement concepts in physical education and exercise science* (pp. 45–72). Champaign: Human Kinetics.

Beauchaine, T. P. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology*, *13*(2), 183–214. https://doi.org/10.1017/S0954579401002012

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal of Psychophysiology*, *98*(2), 338–350. https://doi.org/10.1016/j.ijpsycho.2015.08.004

Beck, J., Lange, S., & Tröster, H. (2016). Geschlechtsunterschiede in der Stressvulnerabilität, Stressbewältigung und Stresssymptomatik bei Grundschulkindern. *Zeitschrift Für Gesundheitspsychologie*, *24*(3), 145–155. https://doi.org/10.1026/0943-8149/a000165

Becker, D. R., Carrère, S., Siler, C., Jones, S., Bowie, B., & Cooke, C. (2012). Autonomic regulation on the stroop predicts reading achievement in school age children. *Mind, Brain, and Education*, *6*(1), 10–18. https://doi.org/10.1111/j.1751-228X.2011.01130.x

Beckerman, H., Roebroeck, M. E., Lankhorst, G. J., Becher, J. G., Bezemer, P. D., & Verbeek, A. L. M. (2001). Smallest real difference, a link between reproducibility and responsiveness. *Quality of Life Research*, *10*(7), 571–578. https://doi.org/10.1023/A:1013138911638

Bedford, D. E. (1951). The ancient art of feeling the pulse. *British Heart Journal*, *13*(4), 423–437. Retrieved from http://heart.bmj.com/content/13/4/423.abstract

Benarroch, E. E. (1993). The central autonomic network: Functional organization, dysfunction, and perspective. *Mayo Clinic Proceedings*, *68*(10), 988–1001. https://doi.org/10.1016/S0025-6196(12)62272-1

Beresnevaitė, M., Benetis, R., Taylor, G. J., Rašinskienė, S., Stankus, A., & Kinduris, S. (2016). Impact of a cognitive behavioral intervention on health-related quality of life and general heart rate variability in patients following cardiac surgery: An effectiveness study. *Psychosomatics*, *57*(6), 605–615. https://doi.org/10.1016/j.psym.2016.04.004

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., … van der Molen, M. W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology*, *34*(6), 623–648. https://doi.org/10.1111/j.1469-8986.1997.tb02140.x

Berntson, G. G., & Cacioppo, J. T. (2004). Heart rate variability: Stress and psychiatric conditions. In M. Malik & A. J. Camm (Eds.), *Dynamic electrocardiography* (pp. 56–63). New York: Futura. https://doi.org/10.1002/9780470987483.ch7

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993). Respiratory sinus arrhythmia: Autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology*, *30*(2), 183–196. https://doi.org/10.1111/j.1469-8986.1993.tb01731.x

Bertsch, K., Hagemann, D., Naumann, E., Schächinger, H., & Schulz, A. (2012). Stability of heart rate variability indices reflecting parasympathetic activity. *Psychophysiology*, *49*(5), 672–682. https://doi.org/10.1111/j.1469-8986.2011.01341.x

Bidwell, A. J., Yazel, B., Davin, D., Fairchild, T. J., & Kanaley, J. A. (2012). Yoga training improves quality of life in women with asthma. *Journal of Alternative and Complementary Medicine*, *18*(8), 749–755. https://doi.org/10.1089/acm.2011.0079

Bigger, J. T., Fleiss, J. L., Rolnitzky, L. M., & Steinman, R. C. (1993). The ability of several short-term measures of RR variability to predict mortality after myocardial infarction. *Circulation*, *88*(3), 927–934. https://doi.org/10.1161/01.CIR.88.3.927

Bilan, A., Witczak, A., Palusiński, R., Myśliński, W., & Hanzlik, J. (2005). Circadian rhythm of spectral indices of heart rate variability in healthy subjects. *Journal of Electrocardiology*, *38*(3), 239–243. https://doi.org/10.1016/j.jelectrocard.2005.01.012

Billman, G. E. (2011). Heart rate variability - a historical perspective. *Frontiers in Physiology*, *2*, 86. https://doi.org/10.3389/fphys.2011.00086

Billman, G. E. (2013). The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. *Frontiers in Physiology*, *4*, 26. https://doi.org/10.3389/fphys.2013.00026

Birch, S. L., Duncan, M. J., & Franklin, C. (2012). Overweight and reduced heart rate variability in British children: An exploratory study. *Preventive Medicine*, *55*(5), 430–432. https://doi.org/10.1016/j.ypmed.2012.09.015

Bland, J. M., & Altman, D. G. (1996a). Statistics notes: Measurement error. *BMJ*, *312*(7047), 1654–1654. https://doi.org/10.1136/bmj.312.7047.1654

Bland, J. M., & Altman, D. G. (1996b). Statistics Notes: Measurement error and correlation coefficients. *BMJ*, *313*(7048), 41–42. https://doi.org/10.1136/bmj.313.7048.41

Bland, J. M., & Altman, D. G. (1996c). Statistics Notes: Measurement error proportional to the mean. *BMJ*, *313*(7049), 106–106. https://doi.org/10.1136/bmj.313.7049.106

Bland, J. M., & Altman, D. G. (1999). Measuring agreement in method comparison studies. *Statistical Methods in Medical Research*, *8*(2), 135–160. https://doi.org/10.1191/096228099673819272

Bland, J. M., & Altman, D. G. (2010). Statistical methods for assessing agreement between two methods of clinical measurement. *International Journal of Nursing Studies*, *47*(8), 931–936. https://doi.org/10.1016/j.ijnurstu.2009.10.001

Blumenthal, J. A., Sherwood, A., Babyak, M. a, Watkins, L. L., Waugh, R., Georgiades, A., … Hinderliter, A. (2005). Effects of exercise and stress management training on markers of cardiovascular risk in patients with ischemic heart disease: A randomized controlled trial. *The Journal of the American Medical Association*, *293*(13), 1626–1634. https://doi.org/10.1097/00008483-200507000-00012

Booij, L., Swenne, C. A., Brosschot, J. F., Haffmans, P. M. J., Thayer, J. F., & Van der Does, A. J. W. (2006). Tryptophan depletion affects heart rate variability and impulsivity in remitted depressed patients with a history of suicidal ideation. *Biological Psychiatry*, *60*(5), 507–514. https://doi.org/10.1016/j.biopsych.2006.02.010

Borg, I. (2003). *Führungsinstrument Mitarbeiterbefragung: Theorien, Tools und Praxiserfahrungen* (3rd ed.). Göttingen: Hogrefe.

Boudreau, P., Yeh, W. H., Dumont, G. A., & Boivin, D. B. (2012). A circadian rhythm in heart rate variability contributes to the increased cardiac sympathovagal response to awakening in the morning. *Chronobiology International*, *29*(6), 757–768. https://doi.org/10.3109/07420528.2012.674592

Brannon, L., Feist, J., & Updegraff, J. A. (2014). *Health psychology: An introduction to behavior and health* (8th ed.). Belmont: Wadsworth, Cengage Learning.

Brdar, I., Rijavec, M., & Loncaric, D. (2006). Goal orientations, coping with school failure and school achievement. *European Journal of Psychology of Education*, *21*(1), 53–70. https://doi.org/10.1007/BF03173569

Brennan, M., Palaniswami, M., & Kamen, P. (2001). Do existing measures of Poincare plot geometry reflect nonlinear features of heart rate variability? *IEEE Transactions on Biomedical Engineering*, *48*(11), 1342–1347. https://doi.org/10.1109/10.959330

Brunetto, A. F., Roseguini, B. T., Silva, B. M., Hirai, D. M., & Guedes, D. P. (2005). Effects of gender and aerobic fitness on cardiac autonomic responses to head-up tilt in healthy adolescents. *Pediatric Cardiology*, *26*(4), 418–424. https://doi.org/10.1007/s00246-004-0808-0

Bruton, A., Conway, J. H., & Holgate, S. T. (2000). Reliability: What is it, and how is it measured? *Physiotherapy*, *86*(2), 94–99. https://doi.org/10.1016/S0031-9406(05)61211-4

Budzynski, T. H., Budzynski, H. K., Maret, K., & Tang, H.-Y. (2008). Heart rate variability enhancement through nanotechnology: A double-blind randomized-control pilot study. *Journal of Neurotherapy*, *12*(1), 45–55. https://doi.org/10.1080/10874200802219905

Bürklein, M., Vogt, L., & Banzer, W. (2005). Messverfahren zur Erfassung der Herzfrequenzvariabilität - Eine vergleichende Studie. *Deutsche Zeitschrift Für Sportmedizin*, *56*(12), 415–421.

Burr, R. L. (2007). Interpretation of normalized spectral heart rate variability indices in sleep research: a critical review. *Sleep*, *30*(7), 913–919. https://doi.org/10.1093/sleep/30.7.913

Campbell, D. T., & Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin*, *56*(2), 81–105. https://doi.org/10.1037/h0046016

Campbell, P. (2008). Escape from the impact factor. *Ethics in Science and Environmental Politics*, *8*(1), 5–7. https://doi.org/10.3354/esep00078

Cannon, W. B. (1929). *Bodily changes in pain, hunger, fear and rage.* New York: Appleton.

Capa, R. L., & Audiffren, M. (2009). How does achievement motivation influence mental effort mobilization? Physiological evidence of deteriorative effects of negative affects on the level of engagement. *International Journal of Psychophysiology*, *74*(3), 236–242. https://doi.org/10.1016/j.ijpsycho.2009.09.007

Carney, R. M., Blumenthal, J. A., Stein, P. K., Watkins, L., Catellier, D., Berkman, L. F., … Freedland, K. E. (2001). Depression, heart rate variability, and acute myocardial infarction. *Circulation*, *104*(17), 2024–2028. https://doi.org/10.1161/hc4201.097834

Carrasco, S., González, R., Gaitán, M. J., & Yáñez, O. (2003). Reproducibility of heart rate variability from short-term recordings during five manoeuvres in normal subjects. *Journal of Medical Engineering & Technology*, *27*(6), 241–248. https://doi.org/10.1080/0309190031000111380

Carter, J. B., Banister, E. W., & Blaber, A. P. (2003). The effect of age and gender on heart rate variability after endurance training. *Medicine and Science in Sports and Exercise*, *35*(8), 1333–1340. https://doi.org/10.1249/01.MSS.0000079046.01763.8F

Caruso, J. F., Brown, L. E., & Tufano, J. J. (2012). The reproducibility of isokinetic dynamometry data. *Isokinetics and Exercise Science*, *20*(4), 239–253. https://doi.org/10.3233/IES-2012-0477

Causey, D. L., & Dubow, E. F. (1992). Development of a self-report coping measure for elementary school children. *Journal of Clinical Child Psychology*, *21*(1), 47–59. https://doi.org/10.1207/s15374424jccp2101_8

Chandola, T., Heraclides, A., & Kumari, M. (2010). Psychophysiological biomarkers of workplace stressors. *Neuroscience & Biobehavioral Reviews*, *35*(1), 51–57. https://doi.org/10.1016/j.neubiorev.2009.11.005

Charlot, K., Cornolo, J., Brugniaux, J. V, Richalet, J. P., & Pichon, A. (2009). Interchangeability between heart rate and photoplethysmography variabilities during sympathetic stimulations. *Physiological Measurement*, *30*(12), 1357–1369. https://doi.org/10.1088/0967-3334/30/12/005

Charmandari, E., Tsigos, C., & Chrousos, G. (2005). Endocrinology of the stress response. *Annual Review of Physiology*, *67*(1), 259–284. https://doi.org/10.1146/annurev.physiol.67.040403.120816

Chemla, D., Young, J., Badilini, F., Maison-Blanche, P., Affres, H., Lecarpentier, Y., & Chanson, P. (2005). Comparison of fast Fourier transform and autoregressive spectral analysis for the study of heart rate variability in diabetic patients. *International Journal of Cardiology*, *104*(3), 307–313. https://doi.org/10.1016/j.ijcard.2004.12.018

Chess, G. F., Tam, R. M., & Calaresu, F. R. (1975). Influence of cardiac neural inputs on rhythmic variations of heart period in the cat. *American Journal of Physiology*, *228*(3), 775–780.

Chrousos, G. P. (2009). Stress and disorders of the stress system. *Nature Reviews Endocrinology*, *5*(7), 374–381. https://doi.org/10.1038/nrendo.2009.106

ChuDuc, H., NguyenPhan, K., & NguyenViet, D. (2013). A review of heart rate variability and its applications. *APCBEE Procedia*, *7*, 80–85. https://doi.org/10.1016/j.apcbee.2013.08.016

Cipryan, L., & Litschmannova, M. (2013). Intra-day and inter-day reliability of heart rate variability measurement. *Journal of Sports Sciences*, *31*(2), 150–158. https://doi.org/10.1080/02640414.2012.721931

Cipryan, L., & Litschmannova, M. (2014). Intra-session stability of short-term heart rate variability measurement: Gender and total spectral power influence. *Journal of Human Sport and Exercise*, *9*(1), 68–80. https://doi.org/10.4100/jhse.2014.91.08

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hilsdale, NJ: Lawrence Erlbaum.

Cohen, S., Kessler, R. C., & Gordon, L. U. (1995). Strategies for measuring stress in studies of psychiatric and physical disorders. In S. Cohen, R. C. Kessler, & L. U. Gordon (Eds.), *Measuring stress: A guide for health and social scientists* (pp. 3–26). New York: Oxford University Press.

Compas, B. E., Connor-Smith, J. K., Saltzman, H., Thomsen, A. H., & Wadsworth, M. E. (2001). Coping with stress during childhood and adolescence: Problems, progress, and potential in theory and research. *Psychological Bulletin*, *127*(1), 87–127. https://doi.org/10.1037//0033-2909.127.1.87

Cooley, J. W., & Tukey, J. W. (1965). An algorithm for the machine calculation of complex Fourier series. *Mathematics of Computation*, *19*(90), 297–301. https://doi.org/10.2307/2003354

Cunningham, M., Hurley, M., Foney, D., & Hayes, D. (2002). Influence of perceived contextual stress on self-esteem and academic outcomes in African American adolescents. *Journal of Black Psychology*, *28*(3), 215–233. https://doi.org/10.1177/0095798402028003003

Cygankiewicz, I., & Zareba, W. (2013). Heart rate variability. *Handbook of Clinical Neurology*, *117*, 379–393. https://doi.org/10.1016/B978-0-444-53491-0.00031-6

De Bock, F., Jarczok, M. N., Hoffmann, K., & Buchhorn, R. (2013). Do our children lose vagus activity? Potential time trends of children's autonomic nervous system activity. *International Journal of Cardiology*, *170*(2), e30–e32. https://doi.org/10.1016/j.ijcard.2013.10.067

de Guevara, M. S. L., Schauffele, S. I., Nicola-Siri, L., Fahrer, R. D., Orti̍z-Frágola, E., Martínez-Martínez, J. A., … Guinjoan, S. M. (2004). Worsening of depressive symptoms 6 months after an acute coronary event in older adults is associated with impairment of cardiac autonomic function. *Journal of Affective Disorders*, *80*(2–3), 257–262. https://doi.org/10.1016/S0165-0327(03)00105-8

De Meersman, R. E. (1993). Heart rate variability and aerobic fitness. *American Heart Journal*, *125*(3), 726–731. https://doi.org/10.1016/0002-8703(93)90164-5

de Vries, S. (2013). *Erfassung der Herzratenvariabilität – ein Leitfaden für Psychologen* (unpublished bachelor's thesis). Chemnitz University of Technology, Chemnitz.

Delaney, J. P. A., & Brodie, D. A. (2000). Effects of short-term psychological stress on the time and frequency domains of heart-rate variability. *Perceptual and Motor Skills*, *91*(2), 515–524. https://doi.org/10.2466/pms.2000.91.2.515

Denver, J. W., Reed, S. F., & Porges, S. W. (2007). Methodological issues in the quantification of respiratory sinus arrhythmia. *Biological Psychology*, *74*(2), 286–294. https://doi.org/10.1016/j.biopsycho.2005.09.005

Dietrich, A., Rosmalen, J. G. M., Althaus, M., van Roon, A., Mulder, L. J. M., Minderaa, R. B., … Riese, H. (2010). Reproducibility of heart rate variability and baroreflex sensitivity measurements in children. *Biological Psychology*, *85*(1), 71–78. https://doi.org/10.1016/j.biopsycho.2010.05.005

Dinas, P. C., Koutedakis, Y., & Flouris, A. D. (2013). Effects of active and passive tobacco cigarette smoking on heart rate variability. *International Journal of Cardiology*, *163*(2), 109–115. https://doi.org/10.1016/j.ijcard.2011.10.140

Dishman, R. K., Jackson, E. M., & Nakamura, Y. (2002). Influence of fitness and gender on blood pressure responses during active or passive stress. *Psychophysiology*, *39*(5), 568–576. https://doi.org/10.1111/1469-8986.3950568

Dishman, R. K., Nakamura, Y., Garcia, M. E., Thompson, R. W., Dunn, A. L., & Blair, S. N. (2000). Heart rate variability, trait anxiety, and perceived stress among physically fit men and women. *International Journal of Psychophysiology*, *37*(2), 121–133. https://doi.org/10.1016/S0167-8760(00)00085-4

Dong, J.-G. (2016). The role of heart rate variability in sports physiology. *Experimental and Therapeutic Medicine*, *11*(5), 1531–1536. https://doi.org/10.3892/etm.2016.3104

Druschky, A., Hilz, M. J., Hopp, P., Platsch, G., Radespiel-Tröger, M., Druschky, K., … Neundörfer, B. (2001). Interictal cardiac autonomic dysfunction in temporal lobe epilepsy demonstrated by [123I]metaiodobenzylguanidine-SPECT. *Brain*, *124*(12), 2372–2382. https://doi.org/10.1093/brain/124.12.2372

Duschek, S., Muckenthaler, M., Werner, N., & Reyes del Paso, G. A. (2009). Relationships between features of autonomic cardiovascular control and cognitive performance. *Biological Psychology*, *81*(2), 110–117. https://doi.org/10.1016/j.biopsycho.2009.03.003

Easterbrook, P. J., Gopalan, R., Berlin, J. A., & Matthews, D. R. (1991). Publication bias in clinical research. *The Lancet*, *337*(8746), 867–872. https://doi.org/10.1016/0140-6736(91)90201-Y

Eckberg, D. L. (1997). Sympathovagal balance: A critical appraisal. *Circulation*, *96*(9), 3224–3232. https://doi.org/10.1161/01.CIR.96.9.3224

Eisenberg, N., Fabes, R. A., Murphy, B., Maszk, P., Smith, M., & Karbon, M. (1995). The role of emotionality and regulation in children's social functioning: A longitudinal study. *Child Development*, *66*(5), 1360–1384. https://doi.org/10.1111/j.1467-8624.1995.tb00940.x

Elkins, A. N., Muth, E., Hoover, A. W., Walker, A. D., Carpenter, T. L., & Switzer, F. S. (2009). Physiological compliance and team performance. *Applied Ergonomics*, *40*(6), 997–1003. https://doi.org/10.1016/j.apergo.2009.02.002

Eller-Berndl, D. (2015). *Herzratenvariabilität* (2nd ed.). Wien: Verlagshaus der Ärzte.

Ellis, R. J., Zhu, B., Koenig, J., Thayer, J. F., & Wang, Y. (2015). A careful look at ECG sampling frequency and R-peak interpolation on short-term measures of heart rate variability. *Physiological Measurement*, *36*(9), 1827–1852. https://doi.org/10.1088/0967-3334/36/9/1827

Ernst, G. (2014). History of heart rate variability. In G. Ernst (Ed.), *Heart rate variability* (pp. 3–8). London: Springer. https://doi.org/10.1007/978-1-4471-4309-3_1

Eschenbeck, H. (2010). Bewältigung alltäglicher Stresssituationen von Kindern und Jugendlichen: Ein Überblick zum Einfluss von Belastungssituation, Alter und Geschlecht. *Zeitschrift Für Gesundheitspsychologie*, *18*(3), 103–118. https://doi.org/10.1026/0943-8149/a000018

Eschenbeck, H., Kohlmann, C.-W., & Lohaus, A. (2007). Gender differences in coping strategies in children and adolescents. *Journal of Individual Differences*, *28*(1), 18–26. https://doi.org/10.1027/1614-0001.28.1.18

Eschenbeck, H., Kohlmann, C.-W., Lohaus, A., & Klein-Heßling, J. (2006). Die Diagnostik von Stressbewältigung mit dem "Fragebogen zur Erhebung von Stress und Stressbewältigung im Kindes- und Jugendalter" (SSKJ 3-8). *Diagnostica*, *52*(3), 131–142. https://doi.org/10.1026/0012-1924.52.3.131

Fabes, R. A., & Eisenberg, N. (1997). Regulatory control and adults' stress-related responses to daily life events. *Journal of Personality and Social Psychology*, *73*(5), 1107–1117. https://doi.org/10.1037/0022-3514.73.5.1107

Fagard, R. H., Pardaens, K., & Staessen, J. A. (1999). Influence of demographic, anthropometric and lifestyle characteristics on heart rate and its variability in the population. *Journal of Hypertension*, *17*(11), 1589–1599. https://doi.org/10.1097/00004872-199917110-00013

Fatisson, J., Oswald, V., & Lalonde, F. (2016). Influence diagram of physiological and environmental factors affecting heart rate variability: an extended literature overview. *Heart International*, *11*(1), 32–40. https://doi.org/10.5301/heartint.5000232

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Felber Dietrich, D., Ackermann-Liebrich, U., Schindler, C., Barthélémy, J.-C., Brändli, O., Gold, D. R., … Gaspoz, J.-M. (2008). Effect of physical activity on heart rate variability in normal weight, overweight and obese subjects: Results from the SAPALDIA study. *European Journal of Applied Physiology*, *104*(3), 557–565. https://doi.org/10.1007/s00421-008-0800-0

Field, A. P. (2009). *Discovering statistics using SPSS* (3rd ed.). London: Sage.

Field, A. P. (2013). *Discovering statistics using IBM SPSS Statistics* (4th ed.). London: Sage.

Flanagan, D. E. H., Pratt, E., Murphy, J., Vaile, J. C., Petley, G. W., Godsland, I. F., & Kerr, D. (2002). Alcohol consumption alters insulin secretion and cardiac autonomic activity. *European Journal of Clinical Investigation*, *32*(3), 187–192. https://doi.org/10.1046/j.1365-2362.2002.00970.x

Flansbjer, U.-B., Holmbäck, A. M., Downham, D., Patten, C., & Lexell, J. (2005). Reliability of gait performance tests in men and women with hemiparesis after stroke. *Journal of Rehabilitation Medicine*, *37*(2), 75–82. https://doi.org/10.1080/16501970410017215

Fleiss, J. L. (1986). Reliability of measurement. In J. L. Fleiss (Ed.), *The design and analysis of clinical experiments* (pp. 1–32). New York: John Wiley and Sons.

Fleming, S., Thompson, M., Stevens, R., Heneghan, C., Plüddemann, A., Maconochie, I., … Mant, D. (2011). Normal ranges of heart rate and respiratory rate in children from birth to 18 years of age: a systematic review of observational studies. *The Lancet*, *377*(9770), 1011–1018. https://doi.org/10.1016/S0140-6736(10)62226-X

Fonseca, D. S., Beda, A., Miranda de Sá, A. M. F. L., & Simpson, D. M. (2013). Gain and coherence estimates between respiration and heart-rate: Differences between inspiration and expiration. *Autonomic Neuroscience*, *178*(2), 89–95. https://doi.org/10.1016/j.autneu.2013.03.015

Francesco, B., Maria Grazia, B., Emanuele, G., Valentina, F., Sara, C., Chiara, F., … Francesco, F. (2012). Linear and nonlinear heart rate variability indexes in clinical practice. *Computational and Mathematical Methods in Medicine*, *2012*, 1–5. https://doi.org/10.1155/2012/219080

Franco, A., Malhotra, N., & Simonovits, G. (2014). Publication bias in the social sciences: Unlocking the file drawer. *Science*, *345*(6203), 1502–1505. https://doi.org/10.1126/science.1255484

Franke, G. H., Jagla, M., Salewski, C., & Jäger, S. (2007). Psychologisch-diagnostische Verfahren zur Erfassung von Stress und Krankheitsbewältigung im deutschsprachigen Raum. *Zeitschrift Für Medizinische Psychologie*, *16*(1,2), 41–55.

Friedman, B. H., Allen, M. T., Christie, I. C., & Santucci, A. K. (2002). Validity concerns of common heart-rate variability indices: Addressing quantification issues in time- and frequency-domain measures of HRV. *IEEE Engineering in Medicine and Biology Magazine*, *21*(4), 35–40. https://doi.org/10.1109/MEMB.2002.1032637

Friedman, B. H., & Thayer, J. F. (1998). Autonomic balance revisited: Panic anxiety and heart rate variability. *Journal of Psychosomatic Research*, *44*(1), 133–151. https://doi.org/10.1016/S0022-3999(97)00202-X

Fujibayashi, M., Matsumoto, T., Kishida, I., Kimura, T., Ishii, C., Ishii, N., & Moritani, T. (2009). Autonomic nervous system activity and psychiatric severity in schizophrenia. *Psychiatry and Clinical Neurosciences*, *63*(4), 538–545. https://doi.org/10.1111/j.1440-1819.2009.01983.x

Fukusaki, C., Kawakubo, K., & Yamamoto, Y. (2000). Assessment of the primary effect of aging on heart rate variability in humans. *Clinical Autonomic Research*, *10*(3), 123–130. https://doi.org/10.1007/BF02278016

Garfield, E. (1972). Citation analysis as a tool in journal evaluation: Journals can be ranked by frequency and impact of citations for science policy studies. *Science*, *178*(4060), 471–479. https://doi.org/10.1126/science.178.4060.471

Gillock, K. L., & Reyes, O. (1999). Stress, support, and academic performance of urban, low-income, Mexican-American adolescents. *Journal of Youth and Adolescence*, *28*(2), 259–282. https://doi.org/10.1023/A:1021657516275

Glanz, K., & Schwartz, M. D. (2008). Stress, coping, and health behavior. In K. Glanz, B. K. Rimer, & K. Viswanath (Eds.), *Health behavior and health education: Theory, research, and practice* (4th ed., pp. 211–236). San Francisco: Jossey-Bass.

Goldberger, A. L. (1990). Nonlinear dynamics, fractals and chaos: Applications to cardiac electrophysiology. *Annals of Biomedical Engineering*, *18*(2), 195–198. https://doi.org/10.1007/BF02368429

Goldberger, A. L. (1996). Non-linear dynamics for clinicians: Chaos theory, fractals, and complexity at the bedside. *The Lancet*, *347*(9011), 1312–1314. https://doi.org/10.1016/S0140-6736(96)90948-4

Goldberger, A. L., Findley, L. J., Blackburn, M. R., & Mandell, A. J. (1984). Nonlinear dynamics in heart failure: Implications of long-wavelength cardiopulmonary oscillations. *American Heart Journal*, *107*(3), 612–615.

Goldberger, A. L., & West, B. J. (1987). Applications of nonlinear dynamics to clinical cardiology. *Annals of the New York Academy of Sciences*, *504*, 195–213. https://doi.org/10.1111/j.1749-6632.1987.tb48733.x

Goldstein, D. S., Bentho, O., Park, M.-Y., & Sharabi, Y. (2011). Low-frequency power of heart rate variability is not a measure of cardiac sympathetic tone but may be a measure of modulation of cardiac autonomic outflows by baroreflexes. *Experimental Physiology*, *96*(12), 1255–1261. https://doi.org/10.1113/expphysiol.2010.056259

González-Pereira, B., Guerrero-Bote, V. P., & Moya-Anegón, F. (2010). A new approach to the metric of journals scientific prestige: The SJR indicator. *Journal of Informetrics*, *4*(3), 379–391. https://doi.org/10.1016/j.joi.2010.03.002

Grimaldi, D., Pierangeli, G., Barletta, G., Terlizzi, R., Plazzi, G., Cevoli, S., … Cortelli, P. (2010). Spectral analysis of heart rate variability reveals an enhanced sympathetic activity in narcolepsy with cataplexy. *Clinical Neurophysiology*, *121*(7), 1142–1147. https://doi.org/10.1016/j.clinph.2010.01.028

Grossman, P. (1983). Respiration, stress, and cardiovascular function. *Psychophysiology*, *20*(3), 284–300. https://doi.org/10.1111/j.1469-8986.1983.tb02156.x

Grossman, P., Beek, J., & Wientjes, C. J. (1990). A comparison of three quantification methods for estimation of respiratory sinus arrhythmia. *Psychophysiology*, *27*(6), 702–714. https://doi.org/10.1111/j.1469-8986.1990.tb03198.x

Grossman, P., Karemaker, J., & Wieling, W. (1991). Prediction of tonic parasympathetic cardiac control using respiratory sinus arrhythima: The need for respiratory control. *Psychophysiology*, *28*(2), 201–216. https://doi.org/10.1111/j.1469-8986.1991.tb00412.x

Grossman, P., & Taylor, E. W. (2007). Toward understanding respiratory sinus arrhythmia: Relations to cardiac vagal tone, evolution and biobehavioral functions. *Biological Psychology*, *74*(2), 263–285. https://doi.org/10.1016/j.biopsycho.2005.11.014

Guijt, A. M., Sluiter, J. K., & Frings-Dresen, M. H. W. (2007). Test-retest reliability of heart rate variability and respiration rate at rest and during light physical activity in normal subjects. *Archives of Medical Research*, *38*(1), 113–120. https://doi.org/10.1016/j.arcmed.2006.07.009

Guinjoan, S. M., Castro, M. N., Vigo, D. E., Weidema, H., Berbara, C., Fahrer, R. D., … Cardinali, D. P. (2007). Depressive symptoms are related to decreased low-frequency heart rate variability in older adults with decompensated heart failure. *Neuropsychobiology*, *55*, 219–224. https://doi.org/10.1159/000108381

Gunnar, M., & Quevedo, K. (2007). The neurobiology of stress and development. *Annual Review of Psychology*, *58*(1), 145–173. https://doi.org/10.1146/annurev.psych.58.110405.085605

Guo, Y.-F., & Stein, P. K. (2002). Circadian rhythm in the cardiovascular system: Considerations in non-invasive electrophysiology. *Cardiac Electrophysiology Review*, *6*(3), 267–272. https://doi.org/10.1023/A:1016337210738

Gutin, B., Howe, C., Johnson, M. H., Humphries, M. C., Snieder, H., & Barbeau, P. (2005). Heart rate variability in adolescents: Relations to physical activity, fitness, and adiposity. *Medicine and Science in Sports and Exercise*, *37*(11), 1856–1863. https://doi.org/10.1249/01.mss.0000175867.98628.27

Hales, S. (1733). *Statical essays: Concerning haemastaticks; Or, an account of some hydraulick and hydrostatical experiments made on the blood and blood vessels of animals*. London: Published by W. Innys and R. Manby.

Hallman, D. M., Srinivasan, D., & Mathiassen, S. E. (2015). Short- and long-term reliability of heart rate variability indices during repetitive low-force work. *European Journal of Applied Physiology*, *115*(4), 803–812. https://doi.org/10.1007/s00421-014-3066-8

Hampel, P., & Petermann, F. (2006). Perceived stress, coping, and adjustment in adolescents. *Journal of Adolescent Health*, *38*(4), 409–415. https://doi.org/10.1016/j.jadohealth.2005.02.014

Hansen, A. L., Dahl, L., Bakke, L., Frøyland, L., & Thayer, J. F. (2010). Fish consumption and heart rate variability. *Journal of Psychophysiology*, *24*(1), 41–47. https://doi.org/10.1027/0269-8803/a000005

Hansen, A. L., Johnsen, B. H., Sollers, J. J., Stenvik, K., & Thayer, J. F. (2004). Heart rate variability and its relation to prefrontal cognitive function: the effects of training and detraining. *European Journal of Applied Physiology*, *93*(3), 263–272. https://doi.org/10.1007/s00421-004-1208-0

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology*, *48*(3), 263–274. https://doi.org/10.1016/S0167-8760(03)00073-4

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2009). Relationship between heart rate variability and cognitive function during threat of shock. *Anxiety, Stress, and Coping*, *22*(1), 77–89. https://doi.org/10.1080/10615800802272251

Hansen, A. L., Kvale, G., Stubhaug, B., & Thayer, J. F. (2013). Heart rate variability and fatigue in patients with chronic fatigue syndrome after a comprehensive cognitive behavior group therapy program. *Journal of Psychophysiology*, *27*(2), 67–75. https://doi.org/10.1027/0269-8803/a000088

Hastings, P. D., Nuselovici, J. N., Utendale, W. T., Coutya, J., McShane, K. E., & Sullivan, C. (2008). Applying the polyvagal theory to children's emotion regulation: Social context, socialization, and adjustment. *Biological Psychology*, *79*(3), 299–306. https://doi.org/10.1016/j.biopsycho.2008.07.005

Hayano, J., Barros, A., Kamiya, A., Ohte, N., & Yasuma, F. (2005). Assessment of pulse rate variability by the method of pulse frequency demodulation. *BioMedical Engineering OnLine*, *4*(1), 62. https://doi.org/10.1186/1475-925X-4-62

Hayano, J., Sakakibara, Y., Yamada, A., Yamada, M., Mukai, S., Fujinami, T., … Takata, K. (1991). Accuracy of assessment of cardiac vagal tone by heart rate variability in normal subjects. *The American Journal of Cardiology*, *67*(2), 199–204.

Hayano, J., Yamada, M., Sakakibara, Y., Fujinami, T., Yokoyama, K., Watanabe, Y., & Takata, K. (1990). Short- and long-term effects of cigarette smoking on heart rate variability. *The American Journal of Cardiology*, *65*(1), 84–88. https://doi.org/10.1016/0002-9149(90)90030-5

Heathers, J. A. J. (2014). Everything Hertz: Methodological issues in short-term frequency-domain HRV. *Frontiers in Physiology*, *5*, 177. https://doi.org/10.3389/fphys.2014.00177

Heilman, K. M. (1997). The neurobiology of emotional experience. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *9*(3), 439–448. https://doi.org/10.1176/jnp.9.3.439

Hirsch, J. A., & Bishop, B. (1981). Respiratory sinus arrhythmia in humans: how breathing pattern modulates heart rate. *American Journal of Physiology - Heart and Circulatory Physiology*, *241*(4), 620–629. Retrieved from http://ajpheart.physiology.org/content/241/4/H620.abstract

Hjortskov, N., Rissén, D., Blangsted, A. K., Fallentin, N., Lundberg, U., & Søgaard, K. (2004). The effect of mental stress on heart rate variability and blood pressure during computer work. *European Journal of Applied Physiology*, *92*(1–2), 84–89. https://doi.org/10.1007/s00421-004-1055-z

Hobfoll, S. E. (1989). Conservation of resources: A new attempt at conceptualizing stress. *American Psychologist*, *44*(3), 513–524. https://doi.org/10.1037/0003-066X.44.3.513

Hoffman, M. A., Levy-Shiff, R., Sohlberg, S. C., & Zarizki, J. (1992). The impact of stress and coping: Developmental changes in the transition to adolescence. *Journal of Youth and Adolescence*, *21*(4), 451–469. https://doi.org/10.1007/BF01537897

Hofmann, S. G., Moscovitch, D. A., Litz, B. T., Kim, H.-J., Davis, L. L., & Pizzagalli, D. A. (2005). The worried mind: Autonomic and prefrontal activation during worrying. *Emotion*, *5*(4), 464–475. https://doi.org/10.1037/1528-3542.5.4.464

Holter, N. J. (1961). New method for heart studies: Continuous electrocardiography of active subjects over long periods is now practical. *Science*, *134*(3486), 1214–1220.

Hon, E., & Lee, S. (1963). Electronic evaluation of the fetal heart rate, VIII. Patterns preceding fetal death: Further observations. *American Journal of Obstetrics and Gynecology*, *87*, 814–826.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*(1), 1–15. https://doi.org/10.2165/00007256-200030010-00001

Hoshi, R. A., Pastre, C. M., Vanderlei, L. C. M., & Godoy, M. F. (2013). Poincaré plot indexes of heart rate variability: Relationships with other nonlinear variables. *Autonomic Neuroscience*, *177*(2), 271–274. https://doi.org/10.1016/j.autneu.2013.05.004

Houghton, A. R., & Gray, D. (2001). *EKG: Von der Kurve zur Diagnose*. München: Urban & Fischer Verlag.

Houtveen, J. H., Rietveld, S., & de Geus, E. J. C. (2002). Contribution of tonic vagal modulation of heart rate, central respiratory drive, respiratory depth, and respiratory frequency to respiratory sinus arrhythmia during mental stress and physical exercise. *Psychophysiology*, *39*(4), 427–436. https://doi.org/10.1017/S0048577202394022

Hoyer, D. (2009). Zur Bedeutung und Analyse der Herzfrequenzvariabilität. *Das Neurophysiologie-Labor*, *31*(3), 158–171. https://doi.org/10.1016/j.neulab.2008.09.005

Huikuri, H. V., Kessler, K. M., Terracall, E., Castellanos, A., Linnaluoto, M. K., & Myerburg, R. J. (1990). Reproducibility and circadian rhythm of heart rate variability in healthy subjects. *The American Journal of Cardiology*, *65*(5), 391–393. https://doi.org/10.1016/0002-9149(90)90308-N

Huikuri, H. V., Mäkikallio, T. H., & Perkiömäki, J. (2003). Measurement of heart rate variability by methods based on nonlinear dynamics. *Journal of Electrocardiology*, *36*, 95–99. https://doi.org/10.1016/j.jelectrocard.2003.09.021

Huikuri, H. V., Ylitalo, A., Pikkujämsä, S. M., Ikäheimo, M. J., Airaksinen, K. E. J., Rantala, A. O., … Kesäniemi, Y. A. (1996). Heart rate variability in systemic hypertension. *The American Journal of Cardiology*, *77*(12), 1073–1077. https://doi.org/10.1016/S0002-9149(96)00135-X

Hyndman, B. W., Kitney, R. I., & Sayers, B. M. (1971). Spontaneous rhythms in physiological control systems. *Nature*, *233*(5318), 339–341. https://doi.org/10.1038/233339a0

Ikawa, M., Tabuse, H., Ueno, S., Urano, T., Sekiya, M., & Murakami, T. (2001). Effects of combination psychotropic drug treatment on heart rate variability in psychiatric patients. *Psychiatry and Clinical Neurosciences*, *55*(4), 341–345. https://doi.org/10.1046/j.1440-1819.2001.00873.x

Jarczok, M. N., Jarczok, M., Mauss, D., Koenig, J., Li, J., Herr, R. M., & Thayer, J. F. (2013). Autonomic nervous system activity and workplace stressors - A systematic review. *Neuroscience & Biobehavioral Reviews*, *37*(8), 1810–1823. https://doi.org/10.1016/j.neubiorev.2013.07.004

Jarrin, D. C., McGrath, J. J., Giovanniello, S., Poirier, P., & Lambert, M. (2012). Measurement fidelity of heart rate variability signal processing: The devil is in the details. *International Journal of Psychophysiology*, *86*(1), 88–97. https://doi.org/10.1016/j.ijpsycho.2012.07.004

Jarrin, D. C., McGrath, J. J., Poirier, P., Séguin, L., Tremblay, R. E., Montplaisir, J. Y., … Séguin, J. R. (2015). Short-term heart rate variability in a population-based sample of 10-year-old children. *Pediatric Cardiology*, *36*(1), 41–48. https://doi.org/10.1007/s00246-014-0962-y

Jenkins, G. M., & Watts, D. G. (1968). *Spectral analysis and its applications*. San Francisco: Holden-Day.

Jones, T., Huggett, S., & Kamalski, J. (2011). Finding a way through the scientific literature: Indexes and measures. *World Neurosurgery*, *76*, 36–38. https://doi.org/10.1016/j.wneu.2011.01.015

Jose, A. D., & Collison, D. (1970). The normal range and determinants of the intrinsic heart rate in man. *Cardiovascular Research*, *4*(2), 160–167.

Kamath, M. V, Watanabe, M. A., & Upton, A. R. M. (2012). Heart rate variability: A historical perspective. In M. V Kamath, M. A. Watanabe, & A. R. M. Upton (Eds.), *Heart rate variability (HRV) signal analysis: Clinical applications* (pp. 1–6). Boca Raton: CRC Press. https://doi.org/doi:10.1201/b12756-2

Kaplan, D. S., Liu, R. X., & Kaplan, H. B. (2005). School related stress in early adolescence and academic performance three years later: The conditional influence of self expectations. *Social Psychology of Education*, *8*(1), 3–17. https://doi.org/10.1007/s11218-004-3129-5

Kaplan, D. T., Furman, M. I., Pincus, S. M., Ryan, S. M., Lipsitz, L. A., & Goldberger, A. L. (1991). Aging and the complexity of cardiovascular dynamics. *Biophysical Journal*, *59*(4), 945–949. https://doi.org/10.1016/S0006-3495(91)82309-8

Karason, K., Mølgaard, H., Wikstrand, J., & Sjöström, L. (1999). Heart rate variability in obesity and the effect of weight loss. *The American Journal of Cardiology*, *83*(8), 1242–1247. https://doi.org/10.1016/S0002-9149(99)00066-1

Kauermann, G., & Küchenhoff, H. (2011). *Stichproben*. Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-12318-4

Kay, S. M., & Marple, S. L. (1981). Spectrum analysis: A modern perspective. *Proceedings of the IEEE*, *69*(11), 1380–1419. https://doi.org/10.1109/PROC.1981.12184

Kemp, A. H., & Quintana, D. S. (2013). The relationship between mental and physical health: Insights from the study of heart rate variability. *International Journal of Psychophysiology*, *89*(3), 288–296. https://doi.org/10.1016/j.ijpsycho.2013.06.018

Kemp, A. H., Quintana, D. S., Felmingham, K. L., Matthews, S., & Jelinek, H. F. (2012). Depression, comorbid anxiety disorders, and heart rate variability in physically healthy, unmedicated patients: Implications for cardiovascular risk. *PLoS ONE*, *7*(2), e30777. https://doi.org/10.1371/journal.pone.0030777

Kemp, A. H., Quintana, D. S., Gray, M. A., Felmingham, K. L., Brown, K., & Gatt, J. M. (2010). Impact of depression and antidepressant treatment on heart rate variability: A review and meta-analysis. *Biological Psychiatry*, *67*(11), 1067–1074. https://doi.org/10.1016/j.biopsych.2009.12.012

Kim, K. K., Kim, J. S., Lim, Y. G., & Park, K. S. (2009). The effect of missing RR-interval data on heart rate variability analysis in the frequency domain. *Physiological Measurement*, *30*(10), 1039–1050. https://doi.org/10.1088/0967-3334/30/10/005

Kim, K. S., & Nam, H. J. (2010). Autonomic nervous function in final year Oriental medical students in Korea: Influence of gender, age and academic performance. *Stress and Health*, *26*(5), 430–436. https://doi.org/10.1002/smi.1316

Kleiger, R. E., Bigger, J. T., Bosner, M. S., Chung, M. K., Cook, J. R., Rolnitzky, L. M., … Fleiss, J. L. (1991). Stability over time of variables measuring heart rate variability in normal subjects. *The American Journal of Cardiology*, *68*(6), 626–630. https://doi.org/10.1016/0002-9149(91)90355-O

Kleiger, R. E., Miller, J. P., Bigger, J. T., & Moss, A. J. (1987). Decreased heart rate variability and its association with increased mortality after acute myocardial infarction. *The American Journal of Cardiology*, *59*(4), 256–262. https://doi.org/10.1016/0002-9149(87)90795-8

Kleiger, R. E., Stein, P. K., & Bigger, J. T. (2005). Heart rate variability: Measurement and clinical utility. *Annals of Noninvasive Electrocardiology*, *10*(1), 88–101. https://doi.org/10.1111/j.1542-474X.2005.10101.x

Kobayashi, H. (2009). Does paced breathing improve the reproducibility of heart rate variability measurements? *Journal of Physiological Anthropology*, *28*(5), 225–230. https://doi.org/10.2114/jpa2.28.225

Koenig, J., Kemp, A. H., Beauchaine, T. P., Thayer, J. F., & Kaess, M. (2016). Depression and resting state heart rate variability in children and adolescents — A systematic review and meta-analysis. *Clinical Psychology Review*, *46*, 136–150. https://doi.org/10.1016/j.cpr.2016.04.013

Koenig, J., & Thayer, J. F. (2016). Sex differences in healthy human heart rate variability: A meta-analysis. *Neuroscience & Biobehavioral Reviews*, *64*, 288–310. https://doi.org/10.1016/j.neubiorev.2016.03.007

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Koskinen, T., Kähönen, M., Jula, A., Laitinen, T., Keltikangas-Järvinen, L., Viikari, J., … Raitakari, O. T. (2009). Short-term heart rate variability in healthy young adults: The Cardiovascular Risk in Young Finns Study. *Autonomic Neuroscience*, *145*, 81–88. https://doi.org/10.1016/j.autneu.2008.10.011

Kowalewski, M. A., & Urban, M. (2004). Short- and long-term reproducibility of autonomic measures in supine and standing positions. *Clinical Science*, *106*(1), 61–66. https://doi.org/10.1042/CS20030119

Krohne, H. W. (2001). Stress and coping theories. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social and behavioral sciences* (pp. 15163–15170). Oxford: Elsevier. https://doi.org/10.1016/B0-08-043076-7/03817-1

Krohne, H. W. (2017). Die Stressreaktion. In H. W. Krohne (Ed.), *Stress und Stressbewältigung bei Operationen* (pp. 7–40). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-662-53000-9_2

Kunz, V. C., Borges, E. N., Coelho, R. C., Gubolino, L. A., Martins, L. E. B., & Silva, E. (2012). Linear and nonlinear analysis of heart rate variability in healthy subjects and after acute myocardial infarction in patients. *Brazilian Journal of Medical and Biological Research*, *45*(5), 450–458. https://doi.org/10.1590/S0100-879X2012007500025

La Rovere, M. T., Pinna, G. D., Maestri, R., Mortara, A., Capomolla, S., Febo, O., … Cobelli, F. (2003). Short-term heart rate variability strongly predicts sudden cardiac death in chronic heart failure patients. *Circulation*, *107*(4), 565–570. https://doi.org/10.1161/01.CIR.0000047275.25795.17

Laborde, S., Mosley, E., & Thayer, J. F. (2017). Heart rate variability and cardiac vagal tone in psychophysiological research – recommendations for experiment planning, data analysis, and data reporting. *Frontiers in Psychology*, *8*, 213. https://doi.org/10.3389/fpsyg.2017.00213

Lackner, H. K., Weiss, E. M., Hinghofer-Szalkay, H., & Papousek, I. (2013). Cardiovascular effects of acute positive emotional arousal. *Applied Psychophysiology and Biofeedback*, *39*(1), 9–18. https://doi.org/10.1007/s10484-013-9235-4

Lane, R. D., McRae, K., Reiman, E. M., Chen, K., Ahern, G. L., & Thayer, J. F. (2009). Neural correlates of heart rate variability during emotion. *NeuroImage*, *44*(1), 213–222. https://doi.org/10.1016/j.neuroimage.2008.07.056

Lazarus, R. S. (1966). *Psychological stress and the coping process*. New York: McGraw-Hill.

Lazarus, R. S. (1993). From psychological stress to the emotions: A history of changing outlooks. *Annual Review of Psychology*, *44*(1), 1–21. https://doi.org/10.1146/annurev.ps.44.020193.000245

Lazarus, R. S., & Cohen, J. B. (1977). Environmental stress. In I. Altman & J. F. Wohlwill (Eds.), *Human behavior and the environment: Current theory and research* (pp. 89–127). New York: Plenum Press.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping*. New York: Springer.

Lazarus, R. S., & Launier, R. (1978). Stress-related transactions between person and environment. In L. A. Pervin & M. Lewis (Eds.), *Perspectives in interactional psychology* (pp. 287–327). New York: Plenum Press.

Levitt, M. J., Guacci-Franco, N., & Levitt, J. L. (1994). Social support and achievement in childhood and early adolescene: A multicultural study. *Journal of Applied Developmental Psychology*, *15*(2), 207–222. https://doi.org/10.1016/0193-3973(94)90013-2

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gotzsche, P. C., Ioannidis, J. P. A., … Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *Journal of Clinical Epidemiology*, *62*(10), 1–34. https://doi.org/10.1016/j.jclinepi.2009.06.006

Licht, C. M. M., de Geus, E. J. C., Zitman, F. G., Hoogendijk, W. J. G., van Dyck, R., & Penninx, B. W. J. H. (2008). Association between major depressive disorder and heart rate variability in the Netherlands study of depression and anxiety (NESDA). *Archives of General Psychiatry*, *65*(12), 1358–1367. https://doi.org/10.1001/archpsyc.65.12.1358

Lohaus, A., Beyer, A., & Klein-Heßling, J. (2004). Stresserleben und Stresssymptomatik bei Kindern und Jugendlichen. *Zeitschrift Für Entwicklungspsychologie Und Pädagogische Psychologie*, *36*(1), 38–46. https://doi.org/10.1026/0049-8637.36.1.38

Lohaus, A., Eschenbeck, H., Kohlmann, C.-W., & Klein-Heßling, J. (2006). *Fragebogen zur Erhebung von Stress und Stressbewältigung im Kindes- und Jugendalter (SSKJ 3-8)*. Göttingen: Hogrefe.

Lohaus, A., Fridrici, M., & Maass, A. (2009). Stressprävention im Jugendalter. *Zeitschrift Für Gesundheitspsychologie*, *17*(1), 13–21. https://doi.org/10.1026/0943-8149.17.1.13

Lotufo, P. A., Valiengo, L., Benseñor, I. M., & Brunoni, A. R. (2012). A systematic review and meta-analysis of heart rate variability in epilepsy and antiepileptic drugs. *Epilepsia*, *53*(2), 272–282. https://doi.org/10.1111/j.1528-1167.2011.03361.x

Lu, C.-L., Zou, X., Orr, W. C., & Chen, J. D. Z. (1999). Postprandial changes of sympathovagal balance measured by heart rate variability. *Digestive Diseases and Sciences*, *44*(4), 857–861. https://doi.org/10.1023/A:1026698800742

Lucini, D., Di Fede, G., Parati, G., & Pagani, M. (2005). Impact of chronic psychosocial stress on autonomic cardiovascular regulation in otherwise healthy subjects. *Hypertension*, *46*(5), 1201–1206. https://doi.org/10.1161/01.HYP.0000185147.32385.4b

Ludwig, C. (1847). Beiträge zur Kenntniss des Einflusses der Respirationsbewegungen auf den Blutlauf im Aortensysteme. *Archiv Für Anatomie, Physiologie Und Wissenschaftliche Medicin*, 242–302.

Lupien, S. J., Maheu, F., Tu, M., Fiocco, A., & Schramek, T. E. (2007). The effects of stress and stress hormones on human cognition: Implications for the field of brain and cognition. *Brain and Cognition*, *65*(3), 209–237. https://doi.org/10.1016/j.bandc.2007.02.007

Luque-Casado, A., Perales, J. C., Cárdenas, D., & Sanabria, D. (2016). Heart rate variability and cognitive processing: The autonomic response to task demands. *Biological Psychology*, *113*, 83–90. https://doi.org/10.1016/j.biopsycho.2015.11.013

MacCann, C., Fogarty, G. J., Zeidner, M., & Roberts, R. D. (2011). Coping mediates the relationship between emotional intelligence (EI) and academic achievement. *Contemporary Educational Psychology*, *36*(1), 60–70. https://doi.org/10.1016/j.cedpsych.2010.11.002

Maestri, R., Raczak, G., Danilowicz-Szymanowicz, L., Torunski, A., Sukiennik, A., Kubica, J., … Pinna, G. D. (2009). Reliability of heart rate variability measurements in patients with a history of myocardial infarction. *Clinical Science*, *118*(3), 195–201. https://doi.org/10.1042/CS20090183

Mahananto, F., Igasaki, T., & Murayama, N. (2015). Potential force dynamics of heart rate variability reflect cardiac autonomic modulation with respect to posture, age, and breathing pattern. *Computers in Biology and Medicine*, *64*, 197–207. https://doi.org/10.1016/j.compbiomed.2015.07.005

Makivić, B., Nikić, M. D., & Willis, M. S. (2013). Heart rate variability (HRV) as a tool for diagnostic and monitoring performance in sport and physical activities. *Journal of Exercise Physiology Online*, *16*(3), 103–131.

Malik, M., & Camm, A. J. (1990). Heart rate variability. *Clinical Cardiology*, *13*(8), 570–576. https://doi.org/10.1002/clc.4960130811

Malliani, A., Pagani, M., Lombardi, F., & Cerutti, S. (1991). Cardiovascular neural regulation explored in the frequency domain. *Circulation*, *84*(2), 482–492. https://doi.org/10.1161/01.CIR.84.2.482

Matthews, S., Jelinek, H., Vafaeiafraz, S., & McLachlan, C. S. (2012). Heart rate stability and decreased parasympathetic heart rate variability in healthy young adults during perceived stress. *International Journal of Cardiology*, *156*(3), 337–338. https://doi.org/10.1016/j.ijcard.2012.02.004

McCraty, R., Atkinson, M., Tiller, W. A., Rein, G., & Watkins, A. D. (1995). The effects of emotions on short-term power spectrum analysis of heart rate variability. *The American Journal of Cardiology*, *76*(14), 1089–1093. https://doi.org/10.1016/S0002-9149(99)80309-9

McDonald, J. D. (2008). Measuring personality constructs: The advantages and disadvantages of self-reports, informant reports and behavioural assessments. *Enquire*, *1*(1), 1–18.

McEwen, B. S., & Sapolsky, R. M. (1995). Stress and cognitive function. *Current Opinion in Neurobiology*, *5*(2), 205–216. https://doi.org/10.1016/0959-4388(95)80028-X

McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological Methods*, *1*(1), 30–46. https://doi.org/10.1037/1082-989X.1.1.30

Michels, N., Clays, E., De Buyzere, M., Huybrechts, I., Marild, S., Vanaelst, B., … Sioen, I. (2013). Determinants and reference values of short-term heart rate variability in children. *European Journal of Applied Physiology*, *113*(6), 1477–1488. https://doi.org/10.1007/s00421-012-2572-9

Michels, N., Sioen, I., Clays, E., De Buyzere, M., Ahrens, W., Huybrechts, I., … De Henauw, S. (2013). Children's heart rate variability as stress indicator: Association with reported stress and cortisol. *Biological Psychology*, *94*(2), 433–440. https://doi.org/10.1016/j.biopsycho.2013.08.005

Miu, A. C., Heilman, R. M., & Miclea, M. (2009). Reduced heart rate variability and vagal tone in anxiety: Trait versus state, and the effects of autogenic training. *Autonomic Neuroscience*, *145*(1–2), 99–103. https://doi.org/10.1016/j.autneu.2008.11.010

Molina–Picó, A., Cuesta–Frau, D., Miró–Martínez, P., Oltra–Crespo, S., & Aboy, M. (2013). Influence of QRS complex detection errors on entropy algorithms. Application to heart rate variability discrimination. *Computer Methods and Programs in Biomedicine*, *110*(1), 2–11. https://doi.org/10.1016/j.cmpb.2012.10.014

Morgenroth, S. (2015). *Lehrerkooperation unter Innovationsstress: Soziale Stressbewältigung als wertvoller Wegweiser*. Wiesbaden: Springer VS. https://doi.org/10.1007/978-3-658-10009-4

Mukherjee, S., Yadav, R., Yung, I., Zajdel, D. P., & Oken, B. S. (2011). Sensitivity to mental effort and test-retest reliability of heart rate variability measures in healthy seniors. *Clinical Neurophysiology*, *122*(10), 2059–2066. https://doi.org/10.1016/j.clinph.2011.02.032

Muñoz, M. L., Van Roon, A., Riese, H., Thio, C., Oostenbroek, E., Westrik, I., … Snieder, H. (2015). Validity of (Ultra-)Short recordings for heart rate variability measurements. *PLoS ONE*, *10*(9), e0138921. https://doi.org/10.1371/journal.pone.0138921

Nunan, D., Sandercock, G. R. H., & Brodie, D. A. (2010). A quantitative systematic review of normal values for short-term heart rate variability in healthy adults. *PACE - Pacing and Clinical Electrophysiology*, *33*(11), 1407–1417. https://doi.org/10.1111/j.1540-8159.2010.02841.x

Nussinovitch, U., Cohen, O., Kaminer, K., Ilani, J., & Nussinovitch, N. (2012). Evaluating reliability of ultra-short ECG indices of heart rate variability in diabetes mellitus patients. *Journal of Diabetes and Its Complications*, *26*(5), 450–453. https://doi.org/10.1016/j.jdiacomp.2012.05.001

Nussinovitch, U., Elishkevitz, K. P., Katz, K., Nussinovitch, M., Segev, S., Volovitz, B., & Nussinovitch, N. (2011). Reliability of ultra-short ECG indices for heart rate variability. *Annals of Noninvasive Electrocardiology*, *16*(2), 117–122. https://doi.org/10.1111/j.1542-474X.2011.00417.x

Nyklíček, I., Mommersteeg, P., Van Beugen, S., Ramakers, C., & Van Boxtel, G. (2013). Mindfulness-based stress reduction and physiological activity during acute stress: A randomized controlled trial. *Health Psychology*, *32*(10), 1110–1113. https://doi.org/10.1037/a0032200

O'Connor, M.-F., Allen, J. J. B., & Kaszniak, A. W. (2002). Autonomic and emotion regulation in bereavement and depression. *Journal of Psychosomatic Research*, *52*(4), 183–185.

O'Regan, C., Kenny, R. A., Cronin, H., Finucane, C., & Kearney, P. M. (2015). Antidepressants strongly influence the relationship between depression and heart rate variability: Findings from The Irish Longitudinal Study on Ageing (TILDA). *Psychological Medicine*, *45*(3), 623–636. https://doi.org/10.1017/S0033291714001767

Ohara, K., Okita, Y., Kouda, K., & Nakamura, H. (2016). Comparison between Fast Fourier Transform and Autoregressive Model on analysis of autonomic nervous function after food intake in women. *Health*, *8*(6), 567–574. https://doi.org/10.4236/health.2016.86060

Oken, B. S., Chamine, I., & Wakeland, W. (2015). A systems approach to stress, stressors and resilience in humans. *Behavioural Brain Research*, *282*, 144–154. https://doi.org/10.1016/j.bbr.2014.12.047

Opthof, T. (2000). The normal range and determinants of the intrinsic heart rate in man. *Cardiovascular Research*, *45*(1), 177–184. https://doi.org/10.1016/S0008-6363(99)00322-3

Oveis, C., Cohen, A. B., Gruber, J., Shiota, M. N., Haidt, J., & Keltner, D. (2009). Resting respiratory sinus arrhythmia is associated with tonic positive emotionality. *Emotion*, *9*(2), 265–270. https://doi.org/10.1037/a0015383

Pagani, M., Lombardi, F., Guzzetti, S., Rimoldi, O., Furlan, R., Pizzinelli, P., … Piccaluga, E. (1986). Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circulation Research*, *59*(2), 178–193. https://doi.org/10.1161/01.RES.59.2.178

Pagani, M., Lombardi, F., Guzzetti, S., Sandrone, G., Rimoldi, O., Malfatto, G., … Malliani, A. (1984). Power spectral density of heart rate variability as an index of sympatho-vagal interaction in normal and hypertensive subjects. *Journal of Hypertension*, *2*(Suppl. 3), 383–385.

Papousek, I., Nauschnegg, K., Paechter, M., Lackner, H. K., Goswami, N., & Schulter, G. (2010). Trait and state positive affect and cardiovascular recovery from experimental academic stress. *Biological Psychology*, *83*(2), 108–115. https://doi.org/10.1016/j.biopsycho.2009.11.008

Papousek, I., Schulter, G., & Premsberger, E. (2002). Dissociated autonomic regulation during stress and physical complaints. *Journal of Psychosomatic Research*, *52*(4), 257–266. https://doi.org/10.1016/S0022-3999(02)00298-2

Parak, J., Tarniceriu, A., Renevey, P., Bertschi, M., Delgado-Gonzalo, R., & Korhonen, I. (2015). Evaluation of the beat-to-beat detection accuracy of PulseOn wearable optical heart rate monitor. In *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 8099–8102). IEEE. https://doi.org/10.1109/EMBC.2015.7320273

Penáz, J., Honzíková, N., & Fiser, B. (1978). Spectral analysis of resting variability of some circulatory parameters in man. *Physiologia Bohemoslovaca*, *27*(4), 349–357.

Peng, S.-M., Koo, M., & Yu, Z.-R. (2009). Effects of music and essential oil inhalation on cardiac autonomic balance in healthy individuals. *The Journal of Alternative and Complementary Medicine*, *15*(1), 53–57. https://doi.org/10.1089/acm.2008.0243

Philippot, P., Chapelle, G., & Blairy, S. (2002). Respiratory feedback in the generation of emotion. *Cognition and Emotion*, *16*(5), 605–627. https://doi.org/10.1080/02699930143000392

Pichon, A., Roulaud, M., Antoine-Jonville, S., De Bisschop, C., & Denjean, A. (2006). Spectral analysis of heart rate variability: Interchangeability between autoregressive analysis and fast Fourier transform. *Journal of Electrocardiology*, *39*(1), 31–37. https://doi.org/10.1016/j.jelectrocard.2005.08.001

Pichot, V., Roche, F., Denis, C., Garet, M., Duverney, D., Costes, F., & Barthélémy, J.-C. (2005). Interval training in elderly men increases both heart rate variability and baroreflex activity. *Clinical Autonomic Research*, *15*(2), 107–115. https://doi.org/10.1007/s10286-005-0251-1

Pinel, J. P. J., & Pauli, P. (2017). *Biopsychologie* (8th ed.). Hallbergmoos: Pearson.

Pinna, G. D., Maestri, R., & Di Cesare, A. (1996). Application of time series spectral analysis theory: analysis of cardiovascular variability signals. *Medical & Biological Engineering & Computing*, *34*(2), 142–148. https://doi.org/10.1007/BF02520019

Pinna, G. D., Maestri, R., La Rovere, M. T., Gobbi, E., & Fanfulla, F. (2006). Effect of paced breathing on ventilatory and cardiovascular variability parameters during short-term investigations of autonomic function. *American Journal of Physiology - Heart and Circulatory Physiology*, *290*(1), 424–433. https://doi.org/10.1152/ajpheart.00438.2005

Pinna, G. D., Maestri, R., Torunski, A., Danilowicz-Szymanowicz, L., Szwoch, M., La Rovere, M. T., & Raczak, G. (2007). Heart rate variability measures: a fresh look at reliability. *Clinical Science*, *113*(3), 131–140. https://doi.org/10.1042/CS20070055

Pitzalis, M. V, Mastropasqua, F., Massari, F., Forleo, C., Di Maggio, M., Passantino, A., … Rizzon, P. (1996). Short- and long-term reproducibility of time and frequency domain heart rate variability measurements in normal subjects. *Cardiovascular Research*, *32*(2), 226–233. https://doi.org/10.1016/0008-6363(96)00086-7

Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of Applied Psychology*, *88*(5), 879–903. https://doi.org/10.1037/0021-9010.88.5.879

Pollatos, O., Füstös, J., & Critchley, H. D. (2012). On the generalised embodiment of pain: How interoceptive sensitivity modulates cutaneous pain perception. *Pain*, *153*(8), 1680–1686. https://doi.org/10.1016/j.pain.2012.04.030

Pop-Jordanova, N., & Chakalaroska, I. (2008). Comparison of biofeedback modalities for better achievement in high school students. *Macedonian Journal of Medical Sciences*, *1*(2), 25–30. https://doi.org/10.3889/MJMS.1857-5773.2008.0020

Porges, S. W. (1995a). Cardiac vagal tone: A physiological index of stress. *Neuroscience & Biobehavioral Reviews*, *19*(2), 225–233. https://doi.org/10.1016/0149-7634(94)00066-A

Porges, S. W. (1995b). Orienting in a defensive world: Mammalian modifications of our evolutionary heritage. A polyvagal theory. *Psychophysiology*, *32*(4), 301–318. https://doi.org/10.1111/j.1469-8986.1995.tb01213.x

Porges, S. W. (2001). The polyvagal theory: Phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology*, *42*(2), 123–146. https://doi.org/10.1016/S0167-8760(01)00162-3

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology*, *74*(2), 116–143. https://doi.org/10.1016/j.biopsycho.2006.06.009

Pumprla, J., Howorka, K., Groves, D., Chester, M., & Nolan, J. (2002). Functional assessment of heart rate variability: physiological basis and practical applications. *International Journal of Cardiology*, *84*(1), 1–14. https://doi.org/10.1016/S0167-5273(02)00057-8

Quintana, D. S., Alvares, G. A., & Heathers, J. A. J. (2016). Guidelines for reporting articles on psychiatry and heart rate variability (GRAPH): Recommendations to advance research communication. *Translational Psychiatry*, *6*(5), 1–10. https://doi.org/10.1038/tp.2016.73

Quintana, D. S., & Heathers, J. A. J. (2014). Considerations in the assessment of heart rate variability in biobehavioral research. *Frontiers in Psychology*, *5*, 805. https://doi.org/10.3389/fpsyg.2014.00805

Radhakrishna, R. K. A., Dutt, D. N., & Yeragani, V. K. (2000). Nonlinear measures of heart rate time series: Influence of posture and controlled breathing. *Autonomic Neuroscience*, *83*(3), 148–158. https://doi.org/10.1016/S1566-0702(00)00173-9

Rauh, R., Burkert, M., Siepmann, M., & Mueck-Weymann, M. (2006). Acute effects of caffeine on heart rate variability in habitual caffeine consumers. *Clinical Physiology and Functional Imaging*, *26*(3), 163–166. https://doi.org/10.1111/j.1475-097X.2006.00663.x

Reed, K. E., Warburton, D. E. ., Whitney, C. L., & McKay, H. A. (2006). Differences in heart rate variability between Asian and Caucasian children living in the same Canadian community. *Applied Physiology, Nutrition, and Metabolism*, *31*(3), 277–282. https://doi.org/10.1139/h05-015

Refinetti, R. (2016). *Circadian Physiology* (3rd ed.). Boca Raton: CRC Press.

Reland, S., Ville, N. S., Wong, S., Senhadji, L., & Carré, F. (2004). Does the level of chronic physical activity alter heart rate variability in healthy older women? *Clinical Science*, *107*(1), 29–35. https://doi.org/10.1042/CS20030405

Rennie, K. L., Hemingway, H., Kumari, M., Brunner, E., Malik, M., & Marmot, M. (2003). Effects of moderate and vigorous physical activity on heart rate variability in a British study of civil servants. *American Journal of Epidemiology*, *158*(2), 135–143. https://doi.org/10.1093/aje/kwg120

Richardson, T., Rozkovec, A., Thomas, P., Ryder, J., Meckes, C., & Kerr, D. (2004). Influence of caffeine on heart rate variability in patients with long-standing type 1 diabetes. *Diabetes Care*, *27*(5), 1127–1131. https://doi.org/10.2337/diacare.27.5.1127

Riganello, F., Candelieri, A., Quintieri, M., Conforti, D., & Dolce, G. (2010). Heart rate variability: An index of brain processing in vegetative state? An artificial intelligence, data mining study. *Clinical Neurophysiology*, *121*(12), 2024–2034. https://doi.org/10.1016/j.clinph.2010.05.010

Riganello, F., Garbarino, S., & Sannita, W. G. (2012). Heart rate variability, homeostasis, and brain function. *Journal of Psychophysiology*, *26*(4), 178–203. https://doi.org/10.1027/0269-8803/a000080

Ritz, T. (2009). Studying noninvasive indices of vagal control: The need for respiratory control and the problem of target specificity. *Biological Psychology*, *80*(2), 158–168. https://doi.org/10.1016/j.biopsycho.2008.08.003

Ritz, T., Thoens, M., & Dahme, B. (2001). Modulation of respiratory sinus arrhythmia by respiration rate and volume: Stability across posture and volume variations. *Psychophysiology*, *38*(5), 858–862. https://doi.org/10.1111/1469-8986.3850858

Rohrmann, T. (2007). Jungen und Mädchen in der Schule. In T. Fleischer, N. Grewe, B. Jötten, K. Seifried, & B. Sieland (Eds.), *Handbuch Schulpsychologie: Psychologie für die Schule* (pp. 221–229). Stuttgart: Kohlhammer.

Rosenthal, R. (1979). The file drawer problem and tolerance for null results. *Psychological Bulletin*, *86*(3), 638–641. https://doi.org/10.1037/0033-2909.86.3.638

Rüdiger, H., Klinghammer, L., & Scheuch, K. (1999). The trigonometric regressive spectral analysis - A method for mapping of beat-to-beat recorded cardiovascular parameters on to frequency domain in comparison with Fourier transformation. *Computer Methods and Programs in Biomedicine*, *58*(1), 1–15. https://doi.org/10.1016/S0169-2607(98)00070-4

Sacha, J. (2013). Why should one normalize heart rate variability with respect to average heart rate. *Frontiers in Physiology*, *4*, 306. https://doi.org/10.3389/fphys.2013.00306

Sacha, J. (2014). Interaction between heart rate and heart rate rariability. *Annals of Noninvasive Electrocardiology*, *19*(3), 207–216. https://doi.org/10.1111/anec.12148

Sacha, J., Barabach, S., Statkiewicz-Barabach, G., Sacha, K., Müller, A., Piskorski, J., … Schmidt, G. (2013). How to strengthen or weaken the HRV dependence on heart rate — Description of the method and its perspectives. *International Journal of Cardiology*, *168*(2), 1660–1663. https://doi.org/10.1016/j.ijcard.2013.03.038

Sacha, J., & Pluta, W. (2005). Different methods of heart rate variability analysis reveal different correlations of heart rate variability spectrum with average heart rate. *Journal of Electrocardiology*, *38*(1), 47–53. https://doi.org/10.1016/j.jelectrocard.2004.09.015

Sacha, J., & Pluta, W. (2008). Alterations of an average heart rate change heart rate variability due to mathematical reasons. *International Journal of Cardiology*, *128*(3), 444–447. https://doi.org/10.1016/j.ijcard.2007.06.047

Sacha, J., Sobon, J., Sacha, K., & Barabach, S. (2013). Heart rate impact on the reproducibility of heart rate variability analysis. *International Journal of Cardiology*, *168*(4), 4257–4259. https://doi.org/10.1016/j.ijcard.2013.04.160

Sammito, S., & Böckelmann, I. (2015). Analyse der Herzfrequenzvariabilität. *Herz*, *40*(Suppl. 1), 76–84. https://doi.org/10.1007/s00059-014-4145-7

Sammito, S., & Böckelmann, I. (2016). Möglichkeiten und Einschränkungen der Herzfrequenzmessung und der Analyse der Herzfrequenzvariabilität mittels mobiler Messgeräte. *Herzschrittmachertherapie and Elektrophysiologie*, *27*(1), 38–45. https://doi.org/10.1007/s00399-016-0419-5

Sammito, S., Thielmann, B., Seibt, R., Klussmann, A., Weippert, M., & Böckelmann, I. (2015). Guideline for the application of heart rate and heart rate variability in occupational medicine and occupational science. *ASU International*, *2015*(6), 1–29. https://doi.org/10.17147/ASUI.2015-06-09-03

Sandercock, G. R. H. (2007). Normative values, reliability and sample size estimates in heart rate variability. *Clinical Science*, *113*(3), 129–130. https://doi.org/10.1042/CS20070137

Sandercock, G. R. H., Bromley, P. D., & Brodie, D. A. (2005). The reliability of short-term measurements of heart rate variability. *International Journal of Cardiology*, *103*(3), 238–247. https://doi.org/10.1016/j.ijcard.2004.09.013

Sandercock, G. R. H., Shelton, C., Bromley, P. D., & Brodie, D. A. (2004). Agreement between three commercially available instruments for measuring short-term heart rate variability. *Physiological Measurement*, *25*(5), 1115–1124. https://doi.org/10.1088/0967-3334/25/5/003

Santos, A. N., Pavão, S. L., Avila, M. A., Salvini, T. F., & Rocha, N. A. C. F. (2013). Reliability of isokinetic evaluation in passive mode for knee flexors and extensors in healthy children. *Brazilian Journal of Physical Therapy*, *17*(2), 112–120. https://doi.org/10.1590/S1413-35552012005000074

Sassi, R., Cerutti, S., Lombardi, F., Malik, M., Huikuri, H. V., Peng, C.-K., … Macfadyen, R. (2015). Advances in heart rate variability signal analysis: joint position statement by the e-Cardiology ESC Working Group and the European Heart Rhythm Association co-endorsed by the Asia Pacific Heart Rhythm Society. *Europace*, *17*(9), 1341–1353. https://doi.org/10.1093/europace/euv015

Sayers, B. M. (1973). Analysis of heart rate variability. *Ergonomics*, *16*(1), 17–32.

Schäfer, A., & Vagedes, J. (2013). How accurate is pulse rate variability as an estimate of heart rate variability? *International Journal of Cardiology*, *166*(1), 15–29. https://doi.org/10.1016/j.ijcard.2012.03.119

Schandry, R. (2016). *Biologische Psychologie* (4th ed.). Weinheim: Beltz.

Schneider, D. (2015). *Erfassung der Herzratenvariabilität bei Kindern - Untersuchung der aktuellen Datenlage und Feasibility von Kurzzeitmessungen im psychologischen Kontext* (unpublished master's thesis). Chemnitz University of Technology, Chemnitz.

Schroeder, E. B., Liao, D., Chambless, L. E., Prineas, R. J., Evans, G. W., & Heiss, G. (2003). Hypertension, blood pressure, and heart rate variability: The atherosclerosis risk in communities (ARIC) study. *Hypertension*, *42*(6), 1106–1111. https://doi.org/10.1161/01.HYP.0000100444.71069.73

Schroeder, E. B., Whitsel, E. A., Evans, G. W., Prineas, R. J., Chambless, L. E., & Heiss, G. (2004). Repeatability of heart rate variability measures. *Journal of Electrocardiology*, *37*(3), 163–172. https://doi.org/10.1016/j.jelectrocard.2004.04.004

Schubert, C., Lambertz, M., Nelesen, R. A., Bardwell, W., Choi, J.-B., & Dimsdale, J. E. (2009). Effects of stress on heart rate complexity - A comparison between short-term and chronic stress. *Biological Psychology*, *80*(3), 325–332. https://doi.org/10.1016/j.biopsycho.2008.11.005

Scimago Lab. (2017). Scimago journal & country rank. Retrieved from http://www.scimagojr.com/

Scully, C., & Lodge, H. (2005). Impact factors and their significance; overrated or misused? *British Dental Journal*, *198*(7), 391–393. https://doi.org/10.1038/sj.bdj.4812185

Seglen, P. O. (1997). Why the impact factor of journals should not be used for evaluating research. *British Medical Journal*, *314*(7079), 498–502.

Seiffge-Krenke, I. (2006). *Nach PISA. Stress in der Schule und mit den Eltern - Bewältigungskompetenz deutscher Jugendlicher im internationalen Vergleich*. Göttingen: Vandenhoeck & Ruprecht.

Seiffge-Krenke, I. (2008). Schulstress in Deutschland: Ursachen, Häufigkeiten und internationale Verortung. *Praxis Der Kinderpsychologie Und Kinderpsychiatrie*, *57*(1), 3–19. https://doi.org/10.13109/prkk.2008.57.1.3

Seiffge-Krenke, I., & Klessinger, N. (2000). Long-term effects of avoidant coping on adolescents' depressive symptoms. *Journal of Youth and Adolescence*, *29*(6), 617–630. https://doi.org/10.1023/A:1026440304695

Seiffge-Krenke, I., & Skaletz, C. (2006). Chronisch krank und auch noch psychisch beeinträchtigt? Die Ergebnisse einer neuen Literaturrecherche. *Praxis Der Kinderpsychologie Und Kinderpsychiatrie*, *55*(1), 73–90.

Seiffge-Krenke, I., & Welter, N. (2008). Mobbing, Bullying und andere Aggressionen unter Schülern als Quelle von Schulstress. *Praxis Der Kinderpsychologie Und Kinderpsychiatrie*, *57*(1), 60–74.

Selye, H. (1974). *Stress without distress*. Philadelphia, New York: Lippincott.

Selye, H. (1976). Forty years of stress research: Principal remaining problems and misconceptions. *Canadian Medical Association Journal*, *115*(1), 53–56.

Shaffer, F., McCraty, R., & Zerr, C. L. (2014). A healthy heart is not a metronome: An integrative review of the heart's anatomy and heart rate variability. *Frontiers in Psychology*, *5*, 1040. https://doi.org/10.3389/fpsyg.2014.01040

Shah, A. J., Su, S., Veledar, E., Bremner, J. D., Goldstein, F. C., Lampert, R., … Vaccarino, V. (2011). Is heart rate variability related to memory performance in middle-aged men? *Psychosomatic Medicine*, *73*(6), 475–482. https://doi.org/10.1097/PSY.0b013e3182227d6a

Sharma, M., Sarin, A., Gupta, P., Sachdeva, S., & Desai, A. (2014). Journal impact factor: its use, significance, and limitations. *World Journal of Nuclear Medicine*, *13*(2), 146. https://doi.org/10.4103/1450-1147.139151

Sharma, R. K., Balhara, Y. P. S., Sagar, R., Deepak, K. K., & Mehta, M. (2011). Heart rate variability study of childhood anxiety disorders. *Journal of Cardiovascular Disease Research*, *2*(2), 115–122. https://doi.org/10.4103/0975-3583.83040

Shrout, P. E. (1998). Measurement reliability and agreement in psychiatry. *Statistical Methods in Medical Research*, *7*(3), 301–317. https://doi.org/10.1191/096228098672090967

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin*, *86*(2), 420–428. https://doi.org/10.1037/0033-2909.86.2.420

Singh, R. B., Weydahl, A., Otsuka, K., Watanabe, Y., Yano, S., Mori, H., … Gvozdjakova, A. (2000). Can nutrition influence circadian rhythm and heart rate variability? *Biomedicine & Pharmacotherapy*, *55*, 115–124. https://doi.org/10.1016/S0753-3322(01)90016-2

Sinnreich, R., Kark, J. D., Friedlander, Y., Sapoznikov, D., & Luria, M. H. (1998). Five minute recordings of heart rate variability for population studies: repeatability and age-sex characteristics. *Heart*, *80*(2), 156–162. https://doi.org/10.1136/hrt.80.2.156

Sole, G., Hamrén, J., Milosavljevic, S., Nicholson, H., & Sullivan, S. J. (2007). Test-retest reliability of isokinetic knee extension and flexion. *Archives of Physical Medicine and Rehabilitation*, *88*(5), 626–631. https://doi.org/10.1016/j.apmr.2007.02.006

Stein, P. K., & Kleiger, R. E. (1999). Insights from the study of heart rate variability. *Annual Review of Medicine*, *50*(1), 249–261. https://doi.org/10.1146/annurev.med.50.1.249

Sterling, T. D. (1959). Publication decisions and their possible effects on inferences drawn from tests of significance - or vice versa. *Journal of the American Statistical Association*, *54*(285), 30–34. https://doi.org/10.2307/2282137

Stewart, S. M., Lam, T. H., Betson, C. L., Wong, C. M., & Wong, A. M. P. (1999). A prospective analysis of stress and academic performance in the first two years of medical school. *Medical Education*, *33*(4), 243–250. https://doi.org/10.1046/j.1365-2923.1999.00294.x

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

Suess, P. E., Porges, S. W., & Plude, D. J. (1994). Cardiac vagal tone and sustained attention in school-age children. *Psychophysiology*, *31*(1), 17–22. https://doi.org/10.1111/j.1469-8986.1994.tb01020.x

Taelman, J., Vandeput, S., Spaepen, A., & Van Huffel, S. (2009). Influence of mental stress on heart rate and heart rate variability. In J. Vander Sloten, P. Verdonck, M. Nyssen, & J. Haueisen (Eds.), *4th European Conference of the International Federation for Medical and Biological Engineering* (pp. 1366–1369). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-540-89208-3_324

Tak, L. M., Riese, H., de Bock, G. H., Manoharan, A., Kok, I. C., & Rosmalen, J. G. M. (2009). As good as it gets? A meta-analysis and systematic review of methodological quality of heart rate variability studies in functional somatic disorders. *Biological Psychology*, *82*(2), 101–110. https://doi.org/10.1016/j.biopsycho.2009.05.002

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal*, *17*(3), 354–381.

https://doi.org/10.1093/oxfordjournals.eurheartj.a014868

Telles, S., Singh, N., & Balkrishna, A. (2011). Heart rate variability changes during high frequency yoga breathing and breath awareness. *Biopsychosocial Medicine*, *5*(4), 1–6. https://doi.org/10.1186/1751-0759-5-4

Thayer, J. F. (2007). What the heart says to the brain (and vice versa) and why we should listen. *Psychological Topics*, *16*, 241–250.

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews*, *36*(2), 747–756. https://doi.org/10.1016/j.neubiorev.2011.11.009

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine*, *37*(2), 141–153. https://doi.org/10.1007/s12160-009-9101-z

Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*, *61*(3), 201–216. https://doi.org/10.1016/S0165-0327(00)00338-4

Thayer, J. F., & Lane, R. D. (2007). The role of vagal function in the risk for cardiovascular disease and mortality. *Biological Psychology*, *74*(2), 224–242. https://doi.org/10.1016/j.biopsycho.2005.11.013

Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart–brain connection: Further elaboration of a model of neurovisceral integration. *Neuroscience & Biobehavioral Reviews*, *33*(2), 81–88. https://doi.org/10.1016/j.neubiorev.2008.08.004

Thayer, J. F., Loerbroks, A., & Sternberg, E. M. (2011). Inflammation and cardiorespiratory control: The role of the vagus nerve. *Respiratory Physiology & Neurobiology*, *178*(3), 387–394. https://doi.org/10.1016/j.resp.2011.05.016

Thayer, J. F., & Siegle, G. J. (2002). Neurovisceral integration in cardiac and emotional regulation. *IEEE Engineering in Medicine and Biology Magazine*, *21*(4), 24–29. https://doi.org/10.1109/MEMB.2002.1032635

Tomson, T., Ericson, M., Ihrman, C., & Lindblad, L. E. (1998). Heart rate variability in patients with epilepsy. *Epilepsy Research*, *30*(1), 77–83. https://doi.org/10.1016/S0920-1211(97)00094-6

Tortora, G. J., & Derrickson, B. H. (2006). *Anatomie und Physiologie*. Weinheim: WILEY-VCH.

Trachani, E., Constantoyannis, C., Sakellaropoulos, G. C., Stavrinou, M. L., Nikiforidis, G., & Chroni,

E. (2012). Heart rate variability in Parkinson's disease unaffected by deep brain stimulation. *Acta Neurologica Scandinavica*, *126*(1), 56–61. https://doi.org/10.1111/j.1600-0404.2011.1605.x

Tressoldi, P. E., Giofré, D., Sella, F., & Cumming, G. (2013). High impact = high statistical standards? Not necessarily so. *PLoS ONE*, *8*(2), e56180. https://doi.org/10.1371/journal.pone.0056180

Tsuji, H., Venditti, F. J., Manders, E. S., Evans, J. C., Larson, M. G., Feldman, C. L., & Levy, D. (1994). Reduced heart rate variability and mortality risk in an elderly cohort. The Framingham Heart Study. *Circulation*, *90*(2), 878–883. https://doi.org/10.1161/01.CIR.90.2.878

Udupa, K., Thirthalli, J., Sathyaprabha, T. N., Kishore, K. R., Raju, T. R., & Gangadhar, B. N. (2011). Differential actions of antidepressant treatments on cardiac autonomic alterations in depression: A prospective comparison. *Asian Journal of Psychiatry*, *4*(2), 100–106. https://doi.org/10.1016/j.ajp.2011.02.006

Valentini, M., & Parati, G. (2009). Variables influencing heart rate. *Progress in Cardiovascular Diseases*, *52*(1), 11–19. https://doi.org/10.1016/j.pcad.2009.05.004

Vazquez, L., Blood, J. D., Wu, J., Chaplin, T. M., Hommer, R. E., Rutherford, H. J. V., … Crowley, M. J. (2016). High frequency heart-rate variability predicts adolescent depressive symptoms, particularly anhedonia, across one year. *Journal of Affective Disorders*, *196*, 243–247. https://doi.org/10.1016/j.jad.2016.02.040

Voss, A., Baier, V., Schulz, S., & Bär, K. J. (2006). Linear and nonlinear methods for analyses of cardiovascular variability in bipolar disorders. *Bipolar Disorders*, *8*(5p1), 441–452. https://doi.org/10.1111/j.1399-5618.2006.00364.x

Voss, A., Schroeder, R., Heitmann, A., Peters, A., & Perz, S. (2015). Short-term heart rate variability - influence of gender and age in healthy subjects. *PLoS ONE*, *10*(3), e0118308. https://doi.org/10.1371/journal.pone.0118308

Vuksanovic, V., Gal, V., Kalanj, J., & Simeunovic, S. (2005). Effect of posture on heart rate variability spectral measures in children and young adults with heart disease. *International Journal of Cardiology*, *101*(2), 273–278. https://doi.org/10.1016/j.ijcard.2004.03.024

Watkins, L. L., Grossman, P., Krishnan, R., & Sherwood, A. (1998). Anxiety and vagal control of heart rate. *Psychosomatic Medicine*, *60*(4), 498–502. https://doi.org/10.1097/00006842-199807000-00018

Weinschenk, S. W., Beise, R. D., & Lorenz, J. (2016). Heart rate variability (HRV) in deep breathing tests and 5-min short-term recordings: Agreement of ear photoplethysmography with ECG measurements, in 343 subjects. *European Journal of Applied Physiology*, *116*(8), 1527–1535. https://doi.org/10.1007/s00421-016-3401-3

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *The Journal of Strength and Conditioning Research*, *19*(1), 231. https://doi.org/10.1519/15184.1

Weis, M., Heikamp, T., & Trommsdorff, G. (2013). Gender differences in school achievement: The role of self-regulation. *Frontiers in Psychology*, *4*, 442. https://doi.org/10.3389/fpsyg.2013.00442

Windle, M., & Windle, R. C. (1996). Coping strategies, drinking motives, and stressful life events among middle adolescents: Associations with emotional and behavioral problems and with academic functioning. *Journal of Abnormal Psychology*, *105*(4), 551–560. https://doi.org/10.1037/0021-843X.105.4.551

Winter, N. (2016). *Stressbewältigung, schulische Leistung und Herzratenvariabilität von Kindern und Jugendlichen* (unpublished master's thesis). Chemnitz University of Technology, Chemnitz.

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, *310*(20), 2191–2194. https://doi.org/10.1001/jama.2013.281053

Young, F. L. S., & Leicht, A. S. (2011). Short-term stability of resting heart rate variability: influence of position and gender. *Applied Physiology, Nutrition, and Metabolism*, *36*(2), 210–218. https://doi.org/10.1139/h10-103

Zahn, D., Adams, J., Krohn, J., Wenzel, M., Mann, C. G., Gomille, L. K., … Kubiak, T. (2016). Heart rate variability and self-control - A meta-analysis. *Biological Psychology*, *115*, 9–26. https://doi.org/10.1016/j.biopsycho.2015.12.007

Zhang, J. (2007). Effect of age and sex on heart rate variability in healthy subjects. *Journal of Manipulative and Physiological Therapeutics*, *30*(5), 374–379. https://doi.org/10.1016/j.jmpt.2007.04.001

Ziegler, A., Antes, G., & König, I. (2011). Bevorzugte Report Items für systematische Übersichten und Meta-Analysen: Das PRISMA-Statement. *Deutsche Medizinische Wochenschrift*, *136*(8), 9–15. https://doi.org/10.1055/s-0031-1272978

Ziemssen, T., Reimann, M., Gasch, J., & Rüdiger, H. (2013). Trigonometric regressive spectral analysis: an innovative tool for evaluating the autonomic nervous system. *Journal of Neural Transmission*, *120*(Suppl. 1), 27–33. https://doi.org/10.1007/s00702-013-1054-5

Ziemssen, T., Süss, M., & Reichmann, H. (2002). The investigation of the cardiovascular part of the autonomic nervous system – an introduction. *Das Neurophysiologie-Labor*, *24*(2), 57–77.

7. Appendix

List of reviewed studies

Aboussafy, D., Campbell, T. S., Lavoie, K., Aboud, F. E., & Ditto, B. (2005). Airflow and autonomic responses to stress and relaxation in asthma: The impact of stressor type. *International Journal of Psychophysiology*, *57*(3), 195–201. https://doi.org/10.1016/j.ijpsycho.2005.02.004

Abrams, D. A., Bhatara, A., Ryali, S., Balaban, E., Levitin, D. J., & Menon, V. (2011). Decoding temporal structure in music and speech relies on shared brain resources but elicits different fine-scale spatial patterns. *Cerebral Cortex*, *21*(7), 1507–1518. https://doi.org/10.1093/cercor/bhq198

Abukonna, A., Yu, X., Zhang, C., & Zhang, J. (2013). Volitional control of the heart rate. *International Journal of Psychophysiology*, *90*(2), 143–148. https://doi.org/10.1016/j.ijpsycho.2013.06.021

Aerts, M. B., Synhaeve, N. E., Mirelman, A., Bloem, B. R., Giladi, N., & Hausdorff, J. M. (2009). Is heart rate variability related to gait impairment in patients with Parkinson's disease? A pilot study. *Parkinsonism and Related Disorders*, *15*(9), 712–715. https://doi.org/10.1016/j.parkreldis.2009.03.001

Agelink, M. W., Boz, C., Ullrich, H., & Andrich, J. (2002). Relationship between major depression and heart rate variability. Clinical consequences and implications for antidepressive treatment. *Psychiatry Research*, *113*(1–2), 139–149. https://doi.org/10.1016/S0165-1781(02)00225-1

Agelink, M. W., Majewski, T., Wurthmann, C., Postert, T., Linka, T., Rotterdam, S., & Klieser, E. (2001). Autonomic neurocardiac function in patients with major depression and effects of antidepressive treatment with nefazodone. *Journal of Affective Disorders*, *62*(3), 187–198. https://doi.org/10.1016/S0165-0327(99)00202-5

Agelink, M. W., Ullrich, H., Baumann, B., Strum, S., & Majewski, T. (2002). Effects of reboxetine, a selective norepinephrine reuptake inhibitor, on sympathetic and parasympathetic outflow to the heart: preliminary data. *Psychopharmacology*, *163*(2), 151–156. https://doi.org/10.1007/s00213-002-1146-7

Agelink, M. W., Zeit, T., Baumann, B., Majewski, T., Postert, T., Lukas, K., & Klieser, E. (2001). In vivo cardiovascular effects of the new atypical neuroleptic sertindole. *International Journal of Psychiatry in Clinical Practice*, *5*(1), 33–40. https://doi.org/10.1080/136515001300225178

Agiovlasitis, S., Collier, S. R., Baynard, T., Echols, G. H., Goulopoulou, S., Figueroa, A., … Fernhall, B. (2010). Autonomic response to upright tilt in people with and without Down syndrome. *Research in Developmental Disabilities*, *31*(3), 857–863. https://doi.org/10.1016/j.ridd.2010.03.002

Ahrens, T., Deuschle, M., Krumm, B., van der Pompe, G., den Boer, J. A., & Lederbogen, F. (2008). Pituitary-adrenal and sympathetic nervous system responses to stress in women remitted from recurrent major depression. *Psychosomatic Medicine*, *70*(4), 461–467. https://doi.org/10.1097/PSY.0b013e31816b1aaa

Åhs, F., Sollers, J. J., Furmark, T., Fredrikson, M., & Thayer, J. F. (2009). High-frequency heart rate variability and cortico-striatal activity in men and women with social phobia. *NeuroImage*, *47*(3), 815–820. https://doi.org/10.1016/j.neuroimage.2009.05.091

Ahsberg, E., Gamberale, F., & Gustafsson, K. (2000). Perceived fatigue after mental work: an experimental evaluation of a fatigue inventory. *Ergonomics*, *43*(2), 252–268. https://doi.org/10.1080/001401300184594

Aldao, A., Mennin, D. S., & McLaughlin, K. A. (2013). Differentiating worry and rumination: Evidence from heart rate variability during spontaneous regulation. *Cognitive Therapy and Research*, *37*(3), 613–619. https://doi.org/10.1007/s10608-012-9485-0

Allan, L. M., Ballard, C. G., Allen, J., Murray, A., Davidson, A. W., McKeith, I. G., & Kenny, R. A. (2007). Autonomic dysfunction in dementia. *Journal of Neurology, Neurosurgery, and Psychiatry*, *78*(7), 671–677. https://doi.org/10.1136/jnnp.2006.102343

Allan, L. M., Kerr, S. R. J., Ballard, C. G., Allen, J., Murray, A., McLaren, A. T., & Kenny, R. A. (2005). Autonomic function assessed by heart rate variability is normal in Alzheimer's disease and vascular dementia. *Dementia and Geriatric Cognitive Disorders*, *19*(2–3), 140–144. https://doi.org/10.1159/000082885

Allen, M. T., Hogan, A. M., & Laird, L. K. (2009). The relationships of impulsivity and cardiovascular responses: The role of gender and task type. *International Journal of Psychophysiology*, *73*(3), 369–376. https://doi.org/10.1016/j.ijpsycho.2009.05.014

Alvarenga, M. E., Richards, J. C., Lambert, G., & Esler, M. D. (2006). Psychophysiological mechanisms in panic disorder: a correlative analysis of noradrenaline spillover, neuronal noradrenaline reuptake, power spectral analysis of heart rate variability, and psychological variables. *Psychosomatic Medicine*, *68*(1), 8–16. https://doi.org/10.1097/01.psy.0000195872.00987.db

Appelhans, B. M., & Luecken, L. J. (2008). Heart rate variability and pain: Associations of two interrelated homeostatic processes. *Biological Psychology*, *77*(2), 174–182. https://doi.org/10.1016/j.biopsycho.2007.10.004

Ashare, R. L., Sinha, R., Lampert, R., Weinberger, A. H., Anderson, G. M., Lavery, M. E., … McKee, S. A. (2012). Blunted vagal reactivity predicts stress-precipitated tobacco smoking. *Psychopharmacology*, *220*(2), 259–268. https://doi.org/10.1007/s00213-011-2473-3

Aslaksen, P. M., & Flaten, M. A. (2008). The roles of physiological and subjective stress in the effectiveness of a placebo on experimentally induced pain. *Psychosomatic Medicine*, *70*(7), 811–818. https://doi.org/10.1097/PSY.0b013e31818105ed

Aslaksen, P. M., Myrbakk, I. N., Høifødt, R. S., & Flaten, M. A. (2007). The effect of experimenter gender on autonomic and subjective responses to pain stimuli. *Pain*, *129*(3), 260–268. https://doi.org/10.1016/j.pain.2006.10.011

Aubert, A. E., Verheyden, B., Beckers, F., Tack, J., & Vandenberghe, J. (2009). Cardiac autonomic regulation under hypnosis assessed by heart rate variability: Spectral analysis and fractal complexity. *Neuropsychobiology*, *60*(2), 104–112. https://doi.org/10.1159/000239686

Baguley, I. J., Heriseanu, R. E., Felmingham, K. L., & Cameron, I. D. (2006). Dysautonomia and heart rate variability following severe traumatic brain injury. *Brain Injury*, *20*(4), 437–444. https://doi.org/10.1080/02699050600664715

Bajkó, Z., Szekeres, C. C., Kovács, K. R., Csapó, K., Molnár, S., Soltész, P., … Csiba, L. (2012). Anxiety, depression and autonomic nervous system dysfunction in hypertension. *Journal of the Neurological Sciences*, *317*(1–2), 112–116. https://doi.org/10.1016/j.jns.2012.02.014

Bakvis, P., Roelofs, K., Kuyk, J., Edelbroek, P. M., Swinkels, W. A. M., & Spinhoven, P. (2009). Trauma, stress, and preconscious threat processing in patients with psychogenic nonepileptic seizures. *Epilepsia*, *50*(5), 1001–1011. https://doi.org/10.1111/j.1528-1167.2008.01862.x

Balanos, G. M., Phillips, A. C., Frenneaux, M. P., McIntyre, D., Lykidis, C., Griffin, H. S., & Carroll, D. (2010). Metabolically exaggerated cardiac reactions to acute psychological stress: The effects of resting blood pressure status and possible underlying mechanisms. *Biological Psychology*, *85*(1), 104–111. https://doi.org/10.1016/j.biopsycho.2010.06.001

Balle, M., Bornas, X., Tortella-Feliu, M., Llabrés, J., Morillas-Romero, A., Aguayo-Siquier, B., & Gelabert, J. M. (2013). Resting parietal EEG asymmetry and cardiac vagal tone predict attentional control. *Biological Psychology*, *93*(2), 257–261. https://doi.org/10.1016/j.biopsycho.2013.02.012

Bär, K. J., Berger, S., Metzner, M., Boettger, M. K., Schulz, S., Ramachandraiah, C. T., … Sauer, H. (2010). Autonomic dysfunction in unaffected first-degree relatives of patients suffering from schizophrenia. *Schizophrenia Bulletin*, *36*(5), 1050–1058. https://doi.org/10.1093/schbul/sbp024

Bär, K. J., Boettger, M. K., Andrich, J., Epplen, J. T., Fischer, F., Cordes, J., … Agelink, M. W. (2008). Cardiovagal modulation upon postural change is altered in Huntington's disease. *European Journal of Neurology*, *15*(8), 869–871. https://doi.org/10.1111/j.1468-1331.2008.02173.x

Bär, K. J., Boettger, M. K., Boettger, S., Grotelüschen, M., Neubauer, R., Jochum, T., … Voss, A. (2006). Reduced baroreflex sensitivity in acute alcohol withdrawal syndrome and in abstained alcoholics. *Drug and Alcohol Dependence*, *85*(1), 66–74. https://doi.org/10.1016/j.drugalcdep.2006.03.014

Bär, K. J., Boettger, M. K., Koschke, M., Boettger, S., Grotelüschen, M., Voss, A., & Yeragani, V. K. (2007). Increased QT interval variability index in acute alcohol withdrawal. *Drug and Alcohol Dependence*, *89*(2–3), 259–266. https://doi.org/10.1016/j.drugalcdep.2007.01.010

Bär, K. J., Boettger, M. K., Koschke, M., Schulz, S., Chokka, P., Yeragani, V. K., & Voss, A. (2007). Non-linear complexity measures of heart rate variability in acute schizophrenia. *Clinical Neurophysiology*, *118*(9), 2009–2015. https://doi.org/10.1016/j.clinph.2007.06.012

Bär, K. J., Boettger, M. K., Schulz, S., Harzendorf, C., Agelink, M. W., Yeragani, V. K., … Voss, A. (2008). The interaction between pupil function and cardiovascular regulation in patients with acute schizophrenia. *Clinical Neurophysiology*, *119*(10), 2209–2213. https://doi.org/10.1016/j.clinph.2008.06.012

Bär, K. J., Boettger, M. K., Schulz, S., Neubauer, R., Jochum, T., Voss, A., & Yeragani, V. K. (2008). Reduced cardio-respiratory coupling in acute alcohol withdrawal. *Drug and Alcohol Dependence*, *98*(3), 210–217. https://doi.org/10.1016/j.drugalcdep.2008.05.012

Bär, K. J., Greiner, W., Jochum, T., Friedrich, M., Wagner, G., & Sauer, H. (2004). The influence of major depression and its treatment on heart rate variability and pupillary light reflex parameters. *Journal of Affective Disorders*, *82*(2), 245–252. https://doi.org/10.1016/j.jad.2003.12.016

Bär, K. J., Koschke, M., Boettger, M. K., Berger, S., Kabisch, A., Sauer, H., … Yeragani, V. K. (2007). Acute psychosis leads to increased QT variability in patients suffering from schizophrenia. *Schizophrenia Research*, *95*(1–3), 115–123. https://doi.org/10.1016/j.schres.2007.05.034

Bär, K. J., Letzsch, A., Jochum, T., Wagner, G., Greiner, W., & Sauer, H. (2005). Loss of efferent vagal activity in acute schizophrenia. *Journal of Psychiatric Research*, *39*(5), 519–527. https://doi.org/10.1016/j.jpsychires.2004.12.007

Bär, K. J., Rachow, T., Schulz, S., Bassarab, K., Haufe, S., Berger, S., … Voss, A. (2012). The phrenic component of acute schizophrenia - a name and its physiological reality. *PLoS ONE*, *7*(3), e33459. https://doi.org/10.1371/journal.pone.0033459

Bär, K. J., Schuhmacher, A., Höfels, S., Schulz, S., Voss, A., Yeragani, V. K., … Zobel, A. (2010). Reduced cardio-respiratory coupling after treatment with nortriptyline in contrast to S-citalopram. *Journal of Affective Disorders*, *127*(1–3), 266–273. https://doi.org/10.1016/j.jad.2010.05.010

Bär, K. J., Schulz, S., Koschke, M., Harzendorf, C., Gayde, S., Berg, W., … Boettger, M. K. (2009). Correlations between the autonomic modulation of heart rate, blood pressure and the pupillary light reflex in healthy subjects. *Journal of the Neurological Sciences*, *279*(1–2), 9–13. https://doi.org/10.1016/j.jns.2009.01.010

Beacher, F. D. C. C., Gray, M. A., Mathias, C. J., & Critchley, H. D. (2009). Vulnerability to simple faints is predicted by regional differences in brain anatomy. *NeuroImage*, *47*(3), 937–945. https://doi.org/10.1016/j.neuroimage.2009.05.038

Beaumont, A., Burton, A. R., Lemon, J., Bennett, B. K., Lloyd, A., & Vollmer-Conna, U. (2012). Reduced cardiac vagal modulation impacts on cognitive performance in chronic fatigue syndrome. *PLoS ONE*, *7*(11), e49518. https://doi.org/10.1371/journal.pone.0049518

Beda, A., Jandre, F. C., Phillips, D. I. W., Giannella-Neto, A., & Simpson, D. M. (2007). Heart-rate and blood-pressure variability during psychophysiological tasks involving speech: Influence of respiration. *Psychophysiology*, *44*(5), 767–778. https://doi.org/10.1111/j.1469-8986.2007.00542.x

Beevers, C. G., Ellis, A. J., & Reid, R. M. (2011). Heart rate variability predicts cognitive reactivity to a sad mood provocation. *Cognitive Therapy and Research*, *35*(5), 395–403. https://doi.org/10.1007/s10608-010-9324-0

Benedetti, F., Colloca, L., Lanotte, M., Bergamasco, B., Torre, E., & Lopiano, L. (2004). Autonomic and emotional responses to open and hidden stimulations of the human subthalamic region. *Brain Research Bulletin*, *63*(3), 203–211. https://doi.org/10.1016/j.brainresbull.2004.01.010

Berger, S., Boettger, M. K., Tancer, M., Guinjoan, S. M., Yeragani, V. K., & Bär, K. J. (2010). Reduced cardio-respiratory coupling indicates suppression of vagal activity in healthy relatives of patients with schizophrenia. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *34*(2), 406–411. https://doi.org/10.1016/j.pnpbp.2010.01.009

Berger, S., Kliem, A., Yeragani, V. K., & Bär, K. J. (2012). Cardio-respiratory coupling in untreated patients with major depression. *Journal of Affective Disorders*, *139*(2), 166–171. https://doi.org/10.1016/j.jad.2012.01.035

Berger, S., Schulz, S., Kletta, C., Voss, A., & Bär, K. J. (2011). Autonomic modulation in healthy first-degree relatives of patients with major depressive disorder. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *35*(7), 1723–1728. https://doi.org/10.1016/j.pnpbp.2011.05.018

Berntson, G. G., Norman, G. J., Hawkley, L. C., & Cacioppo, J. T. (2008). Cardiac autonomic balance versus cardiac regulatory capacity. *Psychophysiology*, *45*(4), 643–652. https://doi.org/10.1111/j.1469-8986.2008.00652.x

Berntson, G. G., Norman, G. J., Hawkley, L. C., & Cacioppo, J. T. (2008). Spirituality and autonomic cardiac control. *Annals of Behavioral Medicine*, *35*(2), 198–208. https://doi.org/10.1007/s12160-008-9027-x

Bertsch, K., Hagemann, D., Naumann, E., Schächinger, H., & Schulz, A. (2012). Stability of heart rate variability indices reflecting parasympathetic activity. *Psychophysiology*, *49*(5), 672–682. https://doi.org/10.1111/j.1469-8986.2011.01341.x

Bidwell, A. J., Yazel, B., Davin, D., Fairchild, T. J., & Kanaley, J. A. (2012). Yoga training improves quality of life in women with asthma. *Journal of Alternative and Complementary Medicine*, *18*(8), 749–755. https://doi.org/10.1089/acm.2011.0079

Bleil, M. E., Gianaros, P. J., Jennings, J. R., Flory, J. D., & Manuck, S. B. (2008). Trait negative affect: Toward an integrated model of understanding psychological risk for impairment in cardiac autonomic function. *Psychosomatic Medicine*, *70*(3), 328–337. https://doi.org/10.1097/PSY.0b013e31816baefa

Blumenthal, J. A., Sherwood, A., Babyak, M. a, Watkins, L. L., Waugh, R., Georgiades, A., … Hinderliter, A. (2005). Effects of exercise and stress management training on markers of cardiovascular risk in patients with ischemic heart disease: A randomized controlled trial. *The Journal of the American Medical Association*, *293*(13), 1626–1634. https://doi.org/10.1097/00008483-200507000-00012

Bob, P., Susta, M., Gregusova, A., & Jasova, D. (2009). Dissociation, cognitive conflict and nonlinear patterns of heart rate dynamics in patients with unipolar depression. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *33*(1), 141–145. https://doi.org/10.1016/j.pnpbp.2008.11.005

Booij, L., Swenne, C. A., Brosschot, J. F., Haffmans, P. M. J., Thayer, J. F., & Van der Does, A. J. W. (2006). Tryptophan depletion affects heart rate variability and impulsivity in remitted depressed patients with a history of cuicidal ideation. *Biological Psychiatry*, *60*(5), 507–514. https://doi.org/10.1016/j.biopsych.2006.02.010

Bornas, X., Gelabert, J. M., Llabrés, J., Balle, M., & Tortella-Feliu, M. (2011). Slope of change throughout exposure treatment for flight phobia: The role of autonomic flexibility. *Journal of Clinical Psychology*, *67*(6), 550–560. https://doi.org/10.1002/jclp.20780

Bornas, X., Llabrés, J., Noguera, M., López, A. M., Barceló, F., Tortella-Feliu, M., & Fullana, M. À. (2005). Looking at the heart of low and high heart rate variability fearful flyers: Self-reported anxiety when confronting feared stimuli. *Biological Psychology*, *70*(3), 182–187. https://doi.org/10.1016/j.biopsycho.2005.01.002

Bornas, X., Llabrés, J., Noguera, M., López, A. M., Barceló, F., Tortella-Feliu, M., & Fullana, M. À. (2004). Self-implication and heart rate variability during simulated exposure to flight-related stimuli. *Anxiety, Stress, and Coping*, *17*(4), 331–339. https://doi.org/10.1080/10615800512331328777

Bornas, X., Llabrés, J., Noguera, M., López, A. M., Gelabert, J. M., & Vila, I. (2006). Fear induced complexity loss in the electrocardiogram of flight phobics: A multiscale entropy analysis. *Biological Psychology*, *73*(3), 272–279. https://doi.org/10.1016/j.biopsycho.2006.05.004

Bornas, X., Llabrés, J., Noguera, M., López, A. M., Tortella-Feliu, M., Fullana, M. À., … Vila, I. (2006). Changes in heart rate variability of flight phobics during a paced breathing task and exposure to fearful stimuli. *International Journal of Clinical and Health Psychology*, *6*(3), 549–563.

Bornas, X., Llabrés, J., Tortella-Feliu, M., Fullana, M. À., Montoya, P., López, A. M., … Gelabert, J. M. (2007). Vagally mediated heart rate variability and heart rate entropy as predictors of treatment outcome in flight phobia. *Biological Psychology*, *76*(3), 188–195. https://doi.org/10.1016/j.biopsycho.2007.07.007

Bornas, X., Riera del Amo, A., Tortella-Feliu, M., & Llabrés, J. (2012). Heart rate variability profiles and exposure therapy treatment outcome in flight phobia. *Applied Psychophysiology and Biofeedback*, *37*, 53–62. https://doi.org/10.1007/s10484-011-9179-5

Bosch, J. A., de Geus, E. J. C., Carroll, D., Goedhart, A. D., Anane, L. A., van Zanten, J. J. V., … Edwards, K. M. (2009). A general enhancement of autonomic and cortisol responses during social evaluative threat. *Psychosomatic Medicine*, *71*(8), 877–885. https://doi.org/10.1097/PSY.0b013e3181baef05

Brandts, J., & Garofalo, O. (2012). Gender pairings and accountability effects. *Journal of Economic Behavior and Organization*, *83*(1), 31–41. https://doi.org/10.1016/j.jebo.2011.06.023

Britton, A., Singh-Manoux, A., Hnatkova, K., Malik, M., Marmot, M., & Shipley, M. (2008). The association between heart rate variability and cognitive impairment in middle-aged men and women: The Whitehall II cohort study. *Neuroepidemiology*, *31*(2), 115–121. https://doi.org/10.1159/000148257

Brody, S., Costa, R. M., & Hess, U. (2012). Sometimes a bear is just a bear: No evidence of nonclinical adult toy animal ownership indicating emotion dysregulation. *Journal of Adult Development*, *19*(3), 177–180. https://doi.org/10.1007/s10804-012-9149-z

Brody, S., & Preut, R. (2003). Vaginal intercourse frequency and heart rate variability. *Journal of Sex & Marital Therapy*, *29*(5), 371–380. https://doi.org/10.1080/00926230390224747

Brody, S., Veit, R., & Rau, H. (2000). A preliminary report relating frequency of vaginal intercourse to heart rate variability, Valsalva ratio, blood pressure, and cohabitation status. *Biological Psychology*, *52*(3), 251–257. https://doi.org/10.1016/S0301-0511(99)00048-4

Brouwer, A.-M., Neerincx, M. A., Kallen, V., van der Leer, L., & ten Brinke, M. (2011). EEG alpha asymmetry, heart rate variability and cortisol in response to virtual reality induced stress. *Journal of Cybertherapy and Rehabilitation*, *4*(1), 27–40.

Brouwer, A.-M., van Wouwe, N., Mühl, C., van Erp, J., & Toet, A. (2013). Perceiving blocks of emotional pictures and sounds: Effects on physiological variables. *Frontiers in Human Neuroscience*, *7*, 295. https://doi.org/10.3389/fnhum.2013.00295

Brunborg, G. S., Johnsen, B. H., Pallesen, S., Molde, H., Mentzoni, R. A., & Myrseth, H. (2010). The relationship between aversive conditioning and risk-avoidance in gambling. *Journal of Gambling Studies*, *26*(4), 545–559. https://doi.org/10.1007/s10899-010-9178-0

Brunoni, A. R., Vanderhasselt, M. A., Boggio, P. S., Fregni, F., Dantas, E. M., Mill, J. G., … Benseñor, I. M. (2013). Polarity- and valence-dependent effects of prefrontal transcranial direct current stimulation on heart rate variability and salivary cortisol. *Psychoneuroendocrinology*, *38*(1), 58–66. https://doi.org/10.1016/j.psyneuen.2012.04.020

Brydon, L. (2011). Adiposity, leptin and stress reactivity in humans. *Biological Psychology*, *86*(2), 114–120. https://doi.org/10.1016/j.biopsycho.2010.02.010

Buchanan, T. W., Driscoll, D., Mowrer, S. M., Sollers, J. J., Thayer, J. F., Kirschbaum, C., & Tranel, D. (2010). Medial prefrontal cortex damage affects physiological and psychological stress responses differently in men and women. *Psychoneuroendocrinology*, *35*(1), 56–66. https://doi.org/10.1016/j.psyneuen.2009.09.006

Buchheit, M., Voss, S. C., Nybo, L., Mohr, M., & Racinais, S. (2011). Physiological and performance adaptations to an in-season soccer camp in the heat: Associations with heart rate and heart rate variability. *Scandinavian Journal of Medicine and Science in Sports*, *21*(6), 477–485. https://doi.org/10.1111/j.1600-0838.2011.01378.x

Buchner, A., & Baumgartner, N. (2007). Text - background polarity affects performance irrespective of ambient illumination and colour contrast. *Ergonomics*, *50*(7), 1036–1063. https://doi.org/10.1080/00140130701306413

Buckman, J. F., White, H. R., & Bates, M. E. (2010). Psychophysiological reactivity to emotional picture cues two years after college students were mandated for alcohol interventions. *Addictive Behaviors*, *35*(8), 786–790. https://doi.org/10.1016/j.addbeh.2010.03.017

Budzynski, T. H., Budzynski, H. K., Maret, K., & Tang, H.-Y. (2008). Heart rate variability enhancement through nanotechnology: A double-blind randomized-control pilot study. *Journal of Neurotherapy*, *12*(1), 45–55. https://doi.org/10.1080/10874200802219905

Burg, J. M., Wolf, O. T., & Michalak, J. (2012). Mindfulness as self-regulated attention: Associations with heart rate variability. *Swiss Journal of Psychology*, *71*(3), 135–139. https://doi.org/10.1024/1421-0185/a000080

Burton, A. R., Birznieks, I., Bolton, P. S., Henderson, L. A., & Macefield, V. G. (2009). Effects of deep and superficial experimentally induced acute pain on muscle sympathetic nerve activity in human subjects. *The Journal of Physiology*, *587*(1), 183–193. https://doi.org/10.1113/jphysiol.2008.162230

Callahan, R. J. (2001). The impact of thought field therapy on heart rate variability. *Journal of Clinical Psychology*, *57*(10), 1153–1170. https://doi.org/10.1002/jclp.1082

Capa, R. L., & Audiffren, M. (2009). How does achievement motivation influence mental effort mobilization? Physiological evidence of deteriorative effects of negative affects on the level of engagement. *International Journal of Psychophysiology*, *74*(3), 236–242. https://doi.org/10.1016/j.ijpsycho.2009.09.007

Capa, R. L., Audiffren, M., & Ragot, S. (2008). The effects of achievement motivation, task difficulty, and goal difficulty on physiological, behavioral, and subjective effort. *Psychophysiology*, *45*(5), 859–868. https://doi.org/10.1111/j.1469-8986.2008.00675.x

Capa, R. L., Audiffren, M., & Ragot, S. (2008). The interactive effect of achievement motivation and task difficulty on mental effort. *International Journal of Psychophysiology*, *70*(2), 144–150. https://doi.org/10.1016/j.ijpsycho.2008.06.007

Capa, R. L., Cleeremans, A., Bustin, G. M., Bouquet, C. a., & Hansenne, M. (2011). Effects of subliminal priming on nonconscious goal pursuit and effort-related cardiovascular response. *Social Cognition*, *29*(4), 430–444. https://doi.org/10.1521/soco.2011.29.4.430

Carter, J. B., Banister, E. W., & Blaber, A. P. (2003). The effect of age and gender on heart rate variability after endurance training. *Medicine and Science in Sports and Exercise*, *35*(8), 1333–1340. https://doi.org/10.1249/01.MSS.0000079046.01763.8F

Castro, M. N., Vigo, D. E., Chu, E. M., Fahrer, R. D., de Achával, D., Costanzo, E. Y., … Guinjoan, S. M. (2009). Heart rate variability response to mental arithmetic stress is abnormal in first-degree relatives of individuals with schizophrenia. *Schizophrenia Research*, *109*, 134–140. https://doi.org/10.1016/j.schres.2008.12.026

Cervantes Blásquez, J. C., Rodas Font, G., & Capdevila Ortís, L. (2009). Heart-rate variability and precompetitive anxiety in swimmers. *Psicothema*, *21*(4), 531–536.

de Guevara, M. S. L., Schauffele, S. I., Nicola-Siri, L., Fahrer, R. D., Ortı́z-Frágola, E., Martínez-Martínez, J. A., … Guinjoan, S. M. (2004). Worsening of depressive symptoms 6 months after an acute coronary event in older adults is associated with impairment of cardiac autonomic function. *Journal of Affective Disorders*, *80*(2–3), 257–262. https://doi.org/10.1016/S0165-0327(03)00105-8

de Manzano, O., Theorell, T., Harmat, L., & Ullén, F. (2010). The psychophysiology of flow during piano playing. *Emotion*, *10*(3), 301–311. https://doi.org/10.1037/a0018432

de Zambotti, M., Covassin, N., Cellini, N., Sarlo, M., & Stegagno, L. (2012). Cardiac autonomic profile during rest and working memory load in essential hypotensive women. *International Journal of Psychophysiology*, *85*(2), 200–205. https://doi.org/10.1016/j.ijpsycho.2012.05.002

DeGiorgio, C. M., Miller, P., Meymandi, S., Chin, A., Epps, J., Gordon, S., … Harper, R. M. (2010). RMSSD, a measure of vagus-mediated heart rate variability, is associated with risk factors for SUDEP: The SUDEP-7 Inventory. *Epilepsy and Behavior*, *19*(1), 78–81. https://doi.org/10.1016/j.yebeh.2010.06.011

DeGiorgio, C. M., Miller, P., Meymandi, S., & Gornbein, J. (2008). n-3 Fatty acids (fish oil) for epilepsy, cardiac risk factors, and risk of SUDEP: Clues from a pilot, double-blind, exploratory study. *Epilepsy and Behavior*, *13*(4), 681–684. https://doi.org/10.1016/j.yebeh.2008.08.001

Del Pozo, J. M., Gevirtz, R. N., Scher, B., & Guarneri, E. (2004). Biofeedback treatment increases heart rate variability in patients with known coronary artery disease. *American Heart Journal*, *147*(3), 545–551. https://doi.org/10.1016/j.ahj.2003.08.013

Delgado-Pastor, L. C., Perakakis, P., Subramanya, P., Telles, S., & Vila, J. (2013). Mindfulness (Vipassana) meditation: Effects on P3b event-related potential and heart rate variability. *International Journal of Psychophysiology*, *90*(2), 207–214. https://doi.org/10.1016/j.ijpsycho.2013.07.006

Demaree, H. A., & Everhart, D. E. (2004). Healthy high-hostiles: Reduced parasympathetic activity and decreased sympathovagal flexibility during negative emotional processing. *Personality and Individual Differences*, *36*(2), 457–469. https://doi.org/10.1016/S0191-8869(03)00109-0

Demaree, H. A., Schmeichel, B., Robinson, J., & Everhart, D. E. (2004). Behavioural, affective, and physiological effects of negative and positive emotional exaggeration. *Cognition and Emotion*, *18*(8), 1079–1097. https://doi.org/10.1080/02699930441000085

Demirci, M., Saribaş, O., Uluç, K., Cekirge, S., Böke, E., & Ay, H. (2006). Carotid artery stenting and endarterectomy have different effects on heart rate variability. *Journal of the Neurological Sciences*, *241*(1–2), 45–51. https://doi.org/10.1016/j.jns.2005.10.011

Denson, T. F., Grisham, J. R., & Moulds, M. L. (2011). Cognitive reappraisal increases heart rate variability in response to an anger provocation. *Motivation and Emotion*, *35*(1), 14–22. https://doi.org/10.1007/s11031-011-9201-5

Dey, A. K., & Mann, D. D. (2010). A complete task analysis to measure the workload associated with operating an agricultural sprayer equipped with a navigation device. *Applied Ergonomics*, *41*(1), 146–149. https://doi.org/10.1016/j.apergo.2009.06.005

DiDomenico, A., & Nussbaum, M. A. (2011). Effects of different physical workload parameters on mental workload and performance. *International Journal of Industrial Ergonomics*, *41*(3), 255–260. https://doi.org/10.1016/j.ergon.2011.01.008

Diego, M. A., & Field, T. (2009). Moderate pressure massage elicits a parasympathetic nervous system response. *The International Journal of Neuroscience*, *119*(5), 630–638. https://doi.org/10.1080/00207450802329605

Dishman, R. K., Jackson, E. M., & Nakamura, Y. (2002). Influence of fitness and gender on blood pressure responses during active or passive stress. *Psychophysiology*, *39*(5), 568–576. https://doi.org/10.1111/1469-8986.3950568

Dishman, R. K., Nakamura, Y., Garcia, M. E., Thompson, R. W., Dunn, A. L., & Blair, S. N. (2000). Heart rate variability, trait anxiety, and perceived stress among physically fit men and women. *International Journal of Psychophysiology*, *37*(2), 121–133. https://doi.org/10.1016/S0167-8760(00)00085-4

Ditto, B., Byrne, N., & Holly, C. (2009). Physiological correlates of applied tension may contribute to reduced fainting during medical procedures. *Annals of Behavioral Medicine*, *37*(3), 306–314. https://doi.org/10.1007/s12160-009-9114-7

Diveky, T., Prasko, J., Kamaradova, D., Grambal, A., Latalova, K., Silhan, P., … Tonhajzerova, I. (2013). Comparison of heart rate variability in patients with panic disorder during cognitive behavioral therapy program. *Psychiatria Danubina*, *25*(1), 62–67.

Dixon-Gordon, K. L., Yiu, A., & Chapman, A. L. (2013). Borderline personality features and emotional reactivity: the mediating role of interpersonal vulnerabilities. *Journal of Behavior Therapy and Experimental Psychiatry*, *44*(2), 271–278. https://doi.org/10.1016/j.jbtep.2012.12.001

Dolbier, C. L., & Rush, T. E. (2012). Efficacy of abbreviated progressive muscle relaxation in a high-stress college sample. *International Journal of Stress Management*, *19*(1), 48–68. https://doi.org/10.1037/a0027326

Dolce, G., Riganello, F., Quintieri, M., Candelieri, A., & Conforti, D. (2008). Personal interaction in the vegetative state: A data-mining study. *Journal of Psychophysiology*, *22*(3), 150–156. https://doi.org/10.1027/0269-8803.22.3.150

Dotti, M. T., Guideri, F., Acampa, M., Orrico, A., Battisti, C., & Federico, A. (2004). Autonomic dysfunction in mental retardation and spastic paraparesis with MECP2 mutation. *Journal of Child Neurology*, *19*(12), 964–966. https://doi.org/10.1177/08830738040190121001

Druschky, A., Hilz, M. J., Hopp, P., Platsch, G., Radespiel-Tröger, M., Druschky, K., … Neundörfer, B. (2001). Interictal cardiac autonomic dysfunction in temporal lobe epilepsy demonstrated by [123I]metaiodobenzylguanidine-SPECT. *Brain*, *124*(12), 2372–2382. https://doi.org/10.1093/brain/124.12.2372

Dulleck, U., Ristl, A., Schaffner, M., & Torgler, B. (2011). Heart rate variability, the autonomic nervous system, and neuroeconomic experiments. *Journal of Neuroscience, Psychology, and Economics*, *4*(2), 117–124. https://doi.org/10.1037/a0022245

Duschek, S., Muckenthaler, M., Werner, N., & Reyes del Paso, G. A. (2009). Relationships between features of autonomic cardiovascular control and cognitive performance. *Biological Psychology*, *81*(2), 110–117. https://doi.org/10.1016/j.biopsycho.2009.03.003

Earnest, C. P., Blair, S. N., & Church, T. S. (2012). Heart rate variability and exercise in aging women. *Journal of Women's Health*, *21*(3), 334–339. https://doi.org/10.1089/jwh.2011.2932

Ebben, M. R., Kurbatov, V., & Pollak, C. P. (2009). Moderating laboratory adaptation with the use of a heart-rate variability biofeedback device (StressEraser®). *Applied Psychophysiology Biofeedback*, *34*(4), 245–249. https://doi.org/10.1007/s10484-009-9086-1

Ebert, A., Jochum, T., Ritter, J., Boettger, M. K., Schulz, S., Voss, A., & Bär, K. J. (2010). Does parasympathetic modulation prior to ECT treatment influence therapeutic outcome? *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *34*(7), 1174–1180. https://doi.org/10.1016/j.pnpbp.2010.06.012

Eddie, D., Buckman, J. F., Mun, E. Y., Vaschillo, B., Vaschillo, E., Udo, T., … Bates, M. E. (2013). Different associations of alcohol cue reactivity with negative alcohol expectancies in mandated and inpatient samples of young adults. *Addictive Behaviors*, *38*(4), 2040–2043. https://doi.org/10.1016/j.addbeh.2013.01.006

Egizio, V. B., Jennings, J. R., Christie, I. C., Sheu, L. K., Matthews, K. A., & Gianaros, P. J. (2008). Cardiac vagal activity during psychological stress varies with social functioning in older women. *Psychophysiology*, *45*(6), 1046–1054. https://doi.org/10.1111/j.1469-8986.2008.00698.x

Elkins, A. N., Muth, E., Hoover, A. W., Walker, A. D., Carpenter, T. L., & Switzer, F. S. (2009). Physiological compliance and team performance. *Applied Ergonomics*, *40*(6), 997–1003. https://doi.org/10.1016/j.apergo.2009.02.002

Eller, N. H., Kristiansen, J., & Hansen, Å. M. (2011). Long-term effects of psychosocial factors of home and work on biomarkers of stress. *International Journal of Psychophysiology*, *79*(2), 195–202. https://doi.org/10.1016/j.ijpsycho.2010.10.009

Elliot, A. J., Payen, V., Brisswalter, J., Cury, F., & Thayer, J. F. (2011). A subtle threat cue, heart rate variability, and cognitive performance. *Psychophysiology*, *48*(10), 1340–1345. https://doi.org/10.1111/j.1469-8986.2011.01216.x

Elsenbruch, S., Lovallo, W. R., & Orr, W. C. (2001). Psychological and physiological responses to postprandial mental stress in women with the irritable bowel syndrome. *Psychosomatic Medicine*, *63*(5), 805–813.

Ergün, U., Demirci, M., Nurlu, G., & Komürcü, F. (2008). Power spectral analysis of heart rate variability: normal values of subjects over 60 years old. *The International Journal of Neuroscience*, *118*(8), 1165–1173. https://doi.org/10.1080/00207450701820845

Eschweiler, G. W., Bartels, M., Längle, G., Wild, B., Gaertner, I., & Nickola, M. (2002). Heart-rate variability (HRV) in the ECG trace of routine EEGs: Fast monitoring for the anticholinergic effects of clozapine and olanzapine? *Pharmacopsychiatry*, *35*(3), 96–100. https://doi.org/10.1055/s-2002-31520

Fagundes, C. P., Murray, D. M., Hwang, B. S., Gouin, J. P., Thayer, J. F., Sollers, J. J., … Kiecolt-Glaser, J. K. (2011). Sympathetic and parasympathetic activity in cancer-related fatigue: More evidence for a physiological substrate in cancer survivors. *Psychoneuroendocrinology*, *36*(8), 1137–1147. https://doi.org/10.1016/j.psyneuen.2011.02.005

Fairclough, S. H., & Houston, K. (2004). A metabolic measure of mental effort. *Biological Psychology*, *66*(2), 177–190. https://doi.org/10.1016/j.biopsycho.2003.10.001

Fairclough, S. H., & Roberts, J. S. (2011). Effects of performance feedback on cardiovascular reactivity and frontal EEG asymmetry. *International Journal of Psychophysiology*, *81*(3), 291–298. https://doi.org/10.1016/j.ijpsycho.2011.07.012

Fang, S. C., Huang, C. J., Yang, T. T., & Tsai, P. S. (2008). Heart rate variability and daytime functioning in insomniacs and normal sleepers: Preliminary results. *Journal of Psychosomatic Research*, *65*(1), 23–30. https://doi.org/10.1016/j.jpsychores.2008.02.003

Farag, N. H., Bardwell, W. A., Nelesen, R. A., Dimsdale, J. E., & Mills, P. J. (2003). Autonomic responses to psychological stress: The influence of menopausal status. *Annals of Behavioral Medicine*, *26*(2), 134–138. https://doi.org/10.1207/S15324796ABM2602_05

Fernández-Lao, C., Cantarero-Villanueva, I., Díaz-Rodríguez, L., Cuesta-Vargas, A. I., Fernández-Delas-Peñas, C., & Arroyo-Morales, M. (2012). Attitudes towards massage modify effects of manual therapy in breast cancer survivors: A randomised clinical trial with crossover design. *European Journal of Cancer Care*, *21*(2), 233–241. https://doi.org/10.1111/j.1365-2354.2011.01306.x

Finkenzeller, T., Doppelmayr, M., & Amesberger, G. (2012). Herzfrequenzvariabilität als Indikator des Aufmerksamkeitsfokus bei Golfern unterschiedlichen Leistungsniveaus. *Zeitschrift Fur Sportpsychologie*, *19*(1), 26–36. https://doi.org/10.1026/1612-5010/a000064

Fraguas, R., Marci, C., Fava, M., Iosifescu, D. V, Bankier, B., Loh, R., & Dougherty, D. D. (2007). Autonomic reactivity to induced emotion as potential predictor of response to antidepressant treatment. *Psychiatry Research*, *151*(1–2), 169–172. https://doi.org/10.1016/j.psychres.2006.08.008

Frasure-Smith, N., Lespérance, F., Irwin, M. R., Talajic, M., & Pollock, B. G. (2009). The relationships among heart rate variability, inflammatory markers and depression in coronary heart disease patients. *Brain, Behavior, and Immunity*, *23*(8), 1140–1147. https://doi.org/10.1016/j.bbi.2009.07.005

Friederich, H.-C., Schild, S., Schellberg, D., Quenter, A., Bode, C., Herzog, W., & Zipfel, S. (2006). Cardiac parasympathetic regulation in obese women with binge eating disorder. *International Journal of Obesity*, *30*(3), 534–542. https://doi.org/10.1038/sj.ijo.0803181

Frustaci, A., Lanza, G. A., Fernandez, I., di Giannantonio, M., & Pozzi, G. (2010). Changes in psychological symptoms and heart rate variability during EMDR treatment: A case series of subthreshold PTSD. *Journal of EMDR Practice and Research*, *4*(1), 3–11. https://doi.org/10.1891/1933-3196.4.1.3

Fujibayashi, M., Matsumoto, T., Kishida, I., Kimura, T., Ishii, C., Ishii, N., & Moritani, T. (2009). Autonomic nervous system activity and psychiatric severity in schizophrenia: Regular article. *Psychiatry and Clinical Neurosciences*, *63*(4), 538–545. https://doi.org/10.1111/j.1440-1819.2009.01983.x

Fujimura, T., & Okanoya, K. (2012). Heart rate variability predicts emotional flexibility in response to positive stimuli. *Psychology*, *3*(8), 578–582. https://doi.org/10.4236/psych.2012.38086

Fujinuma, Y., Asahina, M., Fukushima, T., Katagiri, A., Yamanaka, Y., Misawa, S., & Kuwabara, S. (2012). Preserved autonomic function in patients with POEMS syndrome. *Journal of the Neurological Sciences*, *318*(1–2), 131–134. https://doi.org/10.1016/j.jns.2012.03.004

Fyhri, A., & Phillips, R. O. (2013). Emotional reactions to cycle helmet use. *Accident Analysis and Prevention*, *50*, 59–63. https://doi.org/10.1016/j.aap.2012.03.027

Garakani, A., Martinez, J. M., Aaronson, C. J., Voustianiouk, A., Kaufmann, H., & Gorman, J. M. (2009). Effect of medication and psychotherapy on heart rate variability in panic disorder. *Depression and Anxiety*, *26*(3), 251–258. https://doi.org/10.1002/da.20533

Garcia, R. G., Zarruk, J. G., Guzman, J. C., Barrera, C., Pinzon, A., Trillos, E., … Tomaz, C. (2012). Sex differences in cardiac autonomic function of depressed young adults. *Biological Psychology*, *90*(3), 179–185. https://doi.org/10.1016/j.biopsycho.2012.03.016

Garland, E. L. (2011). Trait mindfulness predicts attentional and autonomic regulation of alcohol cue-reactivity. *Journal of Psychophysiology*, *25*(4), 180–189. https://doi.org/10.1027/0269-8803/a000060

Garland, E. L., Carter, K., Ropes, K., & Howard, M. O. (2012). Thought suppression, impaired regulation of urges, and Addiction-Stroop predict affect-modulated cue-reactivity among alcohol dependent adults. *Biological Psychology*, *89*(1), 87–93. https://doi.org/10.1016/j.biopsycho.2011.09.010

Garland, E. L., Franken, I. H., & Howard, M. O. (2012). Cue-elicited heart rate variability and attentional bias predict alcohol relapse following treatment. *Psychopharmacology*, *222*(1), 17–26. https://doi.org/10.1007/s00213-011-2618-4

Garland, E. L., Franken, I. H., Sheetz, J. J., & Howard, M. O. (2012). Alcohol attentional bias is associated with autonomic indices of stress-primed alcohol cue-reactivity in alcohol-dependent patients. *Experimental and Clinical Psychopharmacology*, *20*(3), 225–235. https://doi.org/10.1037/a0027199

Gass, J. J., & Glaros, A. G. (2013). Autonomic dysregulation in headache patients. *Applied Psychophysiology Biofeedback*, *38*(4), 257–263. https://doi.org/10.1007/s10484-013-9231-8

Gatt, J. M., Nemeroff, C. B., Dobson-Stone, C., Paul, R. H., Bryant, R. A., Schofield, P. R., … Williams, L. M. (2009). Interactions between BDNF Val66Met polymorphism and early life stress predict brain and arousal pathways to syndromal depression and anxiety. *Molecular Psychiatry*, *14*(7), 681–695. https://doi.org/10.1038/mp.2008.143

Geisler, F. C. M., & Kubiak, T. (2009). Heart rate variability predicts self-control in goal pursuit. *European Journal of Personality*, *23*(8), 623–633. https://doi.org/10.1002/per.727

Geisler, F. C. M., Kubiak, T., Siewert, K., & Weber, H. (2013). Cardiac vagal tone is associated with social engagement and self-regulation. *Biological Psychology*, *93*(2), 279–286. https://doi.org/10.1016/j.biopsycho.2013.02.013

Geisler, F. C. M., Vennewald, N., Kubiak, T., & Weber, H. (2010). The impact of heart rate variability on subjective well-being is mediated by emotion regulation. *Personality and Individual Differences*, *49*(7), 723–728. https://doi.org/10.1016/j.paid.2010.06.015

Gershon, P., Shinar, D., & Ronen, A. (2009). Evaluation of experience-based fatigue countermeasures. *Accident Analysis and Prevention*, *41*(5), 969–975. https://doi.org/10.1016/j.aap.2009.05.012

Gevorkyan, E. S., Minasyan, S. M., Adamyan, T. I., Dayan, A. V, & Ksadzhikyan, N. N. (2006). Dynamics of the integrated characteristics of heart rate variability and psychophysiological parameters of students under the conditions of daily and weekly academic loads. *Human Physiology*, *32*(4), 423–428. https://doi.org/10.1134/S0362119706040074

Gianaros, P. J., Salomon, K., Zhou, F., Owens, J. F., Edmundowicz, D., Kuller, L. H., & Matthews, K. A. (2005). A greater reduction in high-frequency heart rate variability to a psychological stressor is associated with subclinical coronary and aortic calcification in postmenopausal women. *Psychosomatic Medicine*, *67*(4), 553–560. https://doi.org/10.1097/01.psy.0000170335.92770.7a

Giardino, N. D., Chan, L., & Borson, S. (2004). Combined heart rate variability and pulse oximetry biofeedback for chronic obstructive pulmonary disease: Preliminary findings. *Applied Psychophysiology and Biofeedback*, *29*(2), 121–133. https://doi.org/10.1023/B:APBI.0000026638.64386.89

Giardino, N. D., Lehrer, P. M., & Edelberg, R. (2002). Comparison of finger plethysmograph to ECG in the measurement of heart rate variability. *Psychophysiology*, *39*(2), 246–253. https://doi.org/10.1017/S0048577202990049

Giese-Davis, J., Wilhelm, F. H., Conrad, A., Abercrombie, H. C., Sephton, S., Yutsis, M., … Spiegel, D. (2006). Depression and stress reactivity in metastatic breast cancer. *Psychosomatic Medicine*, *68*(5), 675–683. https://doi.org/10.1097/01.psy.0000238216.88515.e5

Gilchrist, P. T., & Ditto, B. (2012). The effects of blood-draw and injection stimuli on the vasovagal response. *Psychophysiology*, *49*(6), 815–820. https://doi.org/10.1111/j.1469-8986.2012.01359.x

Ginsberg, J. P., Ayers, E., Burriss, L., & Powell, D. A. (2008). Discriminative delay Pavlovian eyeblink conditioning in veterans with and without posttraumatic stress disorder. *Journal of Anxiety Disorders*, *22*(5), 809–823. https://doi.org/10.1016/j.janxdis.2007.08.009

Ginsberg, J. P., Ayers, E., Burriss, L., & Powell, D. A. (2008). Disruption of bradycardia associated with discriminative conditioning in combat veterans with PTSD. *Neuropsychiatric Disease and Treatment*, *4*(3), 635–646. https://doi.org/10.2147/NDT.S2808

Ginsburg, P., Bartur, G., Peleg, S., Vatine, J. J., & Katz-Leurer, M. (2011). Reproducibility of heart rate variability during rest, paced breathing and light-to-moderate intense exercise in patients one month after stroke. *European Neurology*, *66*(2), 117–122. https://doi.org/10.1159/000329273

Glass, J. M., Lyden, A. K., Petzke, F., Stein, P. K., Whalen, G., Ambrose, K., … Clauw, D. J. (2004). The effect of brief exercise cessation on pain, fatigue, and mood symptom development in healthy, fit individuals. *Journal of Psychosomatic Research*, *57*(4), 391–398. https://doi.org/10.1016/j.jpsychores.2004.04.002

Gordon, J. L., Ditto, B., & D'Antono, B. (2012). Cognitive depressive symptoms associated with delayed heart rate recovery following interpersonal stress in healthy men and women. *Psychophysiology*, *49*(8), 1082–1089. https://doi.org/10.1111/j.1469-8986.2012.01397.x

Gould, K. S., Røed, B. K., Saus, E. R., Koefoed, V. F., Bridger, R. S., & Moen, B. E. (2009). Effects of navigation method on workload and performance in simulated high-speed ship navigation. *Applied Ergonomics*, *40*(1), 103–114. https://doi.org/10.1016/j.apergo.2008.01.001

Grape, C., Sandgren, M., Hansson, L.-O., Ericson, M., & Theorell, T. (2003). Does singing promote well-being?: An empirical study of professional and amateur singers during a singing lesson. *Integrative Physiological and Behavioral Science*, *38*(1), 65–74. https://doi.org/10.1007/BF02734261

Gray, M. A., Rylander, K., Harrison, N. A., Wallin, B. G., & Critchley, H. D. (2009). Following one's heart: Cardiac rhythms gate central initiation of sympathetic reflexes. *Journal of Neuroscience*, *29*(6), 1817–1825. https://doi.org/10.1523/JNEUROSCI.3363-08.2009

Green, M. A., Hallengren, J. J., Davids, C. M., Riopel, C. M., & Skaggs, A. K. (2009). An association between eating disorder behaviors and autonomic dysfunction in a nonclinical population. A pilot study. *Appetite*, *53*(1), 139–142. https://doi.org/10.1016/j.appet.2009.05.005

Grimaldi, D., Pierangeli, G., Barletta, G., Terlizzi, R., Plazzi, G., Cevoli, S., … Cortelli, P. (2010). Spectral analysis of heart rate variability reveals an enhanced sympathetic activity in narcolepsy with cataplexy. *Clinical Neurophysiology*, *121*(7), 1142–1147. https://doi.org/10.1016/j.clinph.2010.01.028

Grote, V., Kelz, C., Goswami, N., Stossier, H., Tafeit, E., & Moser, M. (2013). Cardio-autonomic control and wellbeing due to oscillating color light exposure. *Physiology and Behavior*, *114–115*, 55–64. https://doi.org/10.1016/j.physbeh.2013.03.007

Gruzelier, J. H., Thompson, T., Redding, E., Brandt, R., & Steffert, T. (2014). Application of alpha/theta neurofeedback and heart rate variability training to young contemporary dancers: State anxiety and creativity. *International Journal of Psychophysiology*, *93*(1), 105–111. https://doi.org/10.1016/j.ijpsycho.2013.05.004

Guggisberg, A. G., Mathis, J., Herrmann, U. S., & Hess, C. W. (2007). The functional relationship between yawning and vigilance. *Behavioural Brain Research*, *179*(1), 159–166. https://doi.org/10.1016/j.bbr.2007.01.027

Guinjoan, S. M., Castro, M. N., Vigo, D. E., Weidema, H., Berbara, C., Fahrer, R. D., … Cardinali, D. P. (2007). Depressive symptoms are related to decreased low-frequency heart rate variability in older adults with decompensated heart failure. *Neuropsychobiology*, *55*, 219–224. https://doi.org/10.1159/000108381

Guinjoan, S. M., de Guevara, M. S. L., Correa, C., Schauffele, S. I., Nicola-Siri, L., Fahrer, R. D., … Cardinali, D. P. (2004). Cardiac parasympathetic dysfunction related to depression in older adults with acute coronary syndromes. *Journal of Psychiatric Research*, *56*(1), 83–88. https://doi.org/10.1016/S0022-3999(03)00043-6

Gyurak, A., & Ayduk, Ö. (2008). Resting respiratory sinus arrhythmia buffers against rejection sensitivity via emotion control. *Emotion*, *8*(4), 458–467. https://doi.org/10.1037/1528-3542.8.4.458

Haensch, C. A., Lerch, H., Jörg, J., & Isenmann, S. (2009). Cardiac denervation occurs independent of orthostatic hypotension and impaired heart rate variability in Parkinson's disease. *Parkinsonism and Related Disorders*, *15*(2), 134–137. https://doi.org/10.1016/j.parkreldis.2008.04.031

Hall, S. S., Lightbody, A. A., McCarthy, B. E., Parker, K. J., & Reiss, A. L. (2012). Effects of intranasal oxytocin on social anxiety in males with fragile X syndrome. *Psychoneuroendocrinology*, *37*(4), 509–518. https://doi.org/10.1016/j.psyneuen.2011.07.020

Hallman, D. M., Olsson, E. M. G., von Schéele, B., Melin, L., & Lyskov, E. (2011). Effects of heart rate variability biofeedback in subjects with stress-related chronic neck pain: A pilot study. *Applied Psychophysiology Biofeedback*, *36*(2), 71–80. https://doi.org/10.1007/s10484-011-9147-0

Hamer, M., & Steptoe, A. (2007). Association between physical fitness, parasympathetic control, and proinflammatory responses to mental stress. *Psychosomatic Medicine*, *69*(7), 660–666. https://doi.org/10.1097/PSY.0b013e318148c4c0

Hamilton, L. D., & Meston, C. M. (2011). The role of salivary cortisol and DHEA-S in response to sexual, humorous, and anxiety-inducing stimuli. *Hormones and Behavior*, *59*(5), 765–771. https://doi.org/10.1016/j.yhbeh.2010.12.011

Hammel, J. C., Smitherman, T. A., McGlynn, F. D., Mulfinger, A. M. M., Lazarte, A. A., & Gothard, K. D. (2011). Vagal influence during worry and cognitive challenge. *Anxiety, Stress, and Coping*, *24*(2), 121–136. https://doi.org/10.1080/10615806.2010.490912

Hansen, A. L., Dahl, L., Bakke, L., Frøyland, L., & Thayer, J. F. (2010). Fish consumption and heart rate variability: Preliminary results. *Journal of Psychophysiology*, *24*(1), 41–47. https://doi.org/10.1027/0269-8803/a000005

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2009). Relationship between heart rate variability and cognitive function during threat of shock. *Anxiety, Stress, and Coping*, *22*(1), 77–89. https://doi.org/10.1080/10615800802272251

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology*, *48*(3), 263–274. https://doi.org/10.1016/S0167-8760(03)00073-4

Hansen, A. L., Kvale, G., Stubhaug, B., & Thayer, J. F. (2013). Heart rate variability and fatigue in patients with chronic fatigue syndrome after a comprehensive cognitive behavior group therapy program. *Journal of Psychophysiology*, *27*(2), 67–75. https://doi.org/10.1027/0269-8803/a000088

Harmat, L., Ullen, F., de Manzano, O., Olsson, E. M. G., Elofsson, U., von Schéele, B., & Theorell, T. (2011). Heart rate variability during piano playing: A case study of three professional solo pianists playing a self-selected and a difficult prima vista piece. *Music and Medicine*, *3*(2), 102–107. https://doi.org/10.1177/1943862110387158

Harrison, N. A., Cooper, E., Voon, V., Miles, K., & Critchley, H. D. (2013). Central autonomic network mediates cardiovascular responses to acute inflammation: Relevance to increased cardiovascular risk in depression? *Brain, Behavior, and Immunity*, *31*, 189–196. https://doi.org/10.1016/j.bbi.2013.02.001

Harte, C. B., Liverant, G. I., Sloan, D. M., Kamholz, B. W., Rosebrock, L. E., Fava, M., & Kaplan, G. B. (2013). Association between smoking and heart rate variability among individuals with depression. *Annals of Behavioral Medicine*, *46*(1), 73–80. https://doi.org/10.1007/s12160-013-9476-8

Hassett, A., Radvanski, D., Vaschillo, E., Vaschillo, B., Sigal, L. H., Karavidas, M. K., … Lehrer, P. M. (2007). A pilot study of the efficacy of heart rate variability (HRV) biofeedback in patients with fibromyalgia. *Applied Psychophysiology and Biofeedback*, *32*(1), 1–10. https://doi.org/10.1007/s10484-006-9028-0

Hauschildt, M., Peters, M. J. V, Moritz, S., & Jelinek, L. (2011). Heart rate variability in response to affective scenes in posttraumatic stress disorder. *Biological Psychology*, *88*(2–3), 215–222. https://doi.org/10.1016/j.biopsycho.2011.08.004

Hawkins, M. A. W., Stewart, J. C., Fitzgerald, G. J., & Kim, S. (2011). Combined effect of depressive symptoms and hostility on autonomic nervous system function. *International Journal of Psychophysiology*, *81*(3), 317–323. https://doi.org/10.1016/j.ijpsycho.2011.07.018

Heathers, J. A. J. (2013). Smartphone-enabled pulse rate variability: An alternative methodology for the collection of heart rate variability in psychophysiological research. *International Journal of Psychophysiology*, *89*(3), 297–304. https://doi.org/10.1016/j.ijpsycho.2013.05.017

Heilman, K. J., Handelman, M., Lewis, G., & Porges, S. W. (2008). Accuracy of the StressEraser® in the detection of cardiac rhythms. *Applied Psychophysiology Biofeedback*, *33*(2), 83–89. https://doi.org/10.1007/s10484-008-9054-1

Heilman, K. J., Harden, E. R., Weber, K. M., Cohen, M., & Porges, S. W. (2013). Atypical autonomic regulation, auditory processing, and affect recognition in women with HIV. *Biological Psychology*, *94*(1), 143–151. https://doi.org/10.1016/j.biopsycho.2013.06.003

Heilman, K. J., & Porges, S. W. (2007). Accuracy of the LifeShirt® (Vivometrics) in the detection of cardiac rhythms. *Biological Psychology*, *75*(3), 300–305. https://doi.org/10.1016/j.biopsycho.2007.04.001

Heindl, S., Holzschneider, J., Hinz, A., Sayk, F., Fehm, H. L., & Dodt, C. (2006). Acute effects of aldosterone on the autonomic nervous system and the baroreflex function in healthy humans. *Journal of Neuroendocrinology*, *18*(2), 115–121. https://doi.org/10.1111/j.1365-2826.2005.01392.x

Hempel, R. J., Tulen, J. H. M., van Beveren, N. J. M., Röder, C. H., & Hengeveld, M. W. (2009). Cardiovascular variability during treatment with haloperidol, olanzapine or risperidone in recent-onset schizophrenia. *Journal of Psychopharmacology*, *23*(6), 697–707. https://doi.org/10.1177/0269881108091254

Henning, R. A., Armstead, A. G., & Ferris, J. K. (2009). Social psychophysiological compliance in a four-person research team. *Applied Ergonomics*, *40*(6), 1004–1010. https://doi.org/10.1016/j.apergo.2009.04.009

Henriques, G., Keffer, S., Abrahamson, C., & Horst, S. J. (2011). Exploring the effectiveness of a computer-based heart rate variability biofeedback program in reducing anxiety in college students. *Applied Psychophysiology Biofeedback*, *36*(2), 101–112. https://doi.org/10.1007/s10484-011-9151-4

Henry, B. L., Minassian, A., Paulus, M. P., Geyer, M. A., & Perry, W. (2010). Heart rate variability in bipolar mania and schizophrenia. *Journal of Psychiatric Research*, *44*(3), 168–176. https://doi.org/10.1016/j.jpsychires.2009.07.011

Henry, B. L., Minassian, A., & Perry, W. (2012). Effect of methamphetamine dependence on heart rate variability. *Addiction Biology*, *17*(3), 648–658. https://doi.org/10.1111/j.1369-1600.2010.00270.x

Herbert, B. M., Pollatos, O., Flor, H., Enck, P., & Schandry, R. (2010). Cardiac awareness and autonomic cardiac reactivity during emotional picture viewing and mental stress. *Psychophysiology*, *47*(2), 342–354. https://doi.org/10.1111/j.1469-8986.2009.00931.x

Herbsleb, M., Schulz, S., Ostermann, S., Donath, L., Eisenträger, D., Puta, C., … Bär, K. J. (2013). The relation of autonomic function to physical fitness in patients suffering from alcohol dependence. *Drug and Alcohol Dependence*, *132*(3), 505–512. https://doi.org/10.1016/j.drugalcdep.2013.03.016

Hibbert, A. S., Weinberg, A., & Klonsky, E. D. (2012). Field validity of heart rate variability metrics produced by QRSTool and CMetX. *Psychological Assessment*, *24*(3), 777–782. https://doi.org/10.1037/a0027284

Hilbert, A., Vögele, C., Tuschen-Caffier, B., & Hartmann, A. S. (2011). Psychophysiological responses to idiosyncratic stress in bulimia nervosa and binge eating disorder. *Physiology and Behavior*, *104*(5), 770–777. https://doi.org/10.1016/j.physbeh.2011.07.013

Hinds, A. L., Woody, E. Z., Drandic, A., Schmidt, L. A., Van Ameringen, M., Coroneos, M., & Szechtman, H. (2010). The psychology of potential threat: Properties of the security motivation system. *Biological Psychology*, *85*(2), 331–337. https://doi.org/10.1016/j.biopsycho.2010.08.003

Hintsanen, M., Elovainio, M., Puttonen, S., Kivimäki, M., Koskinen, T., Raitakari, O. T., & Keltikangas-Järvinen, L. (2007). Effort-reward imbalance, heart rate, and heart rate variability: The cardiovascular risk in young Finns study. *International Journal of Behavioral Medicine*, *14*(4), 202–212. https://doi.org/10.1080/10705500701638369

Hofmann, S. G., Moscovitch, D. A., Litz, B. T., Kim, H.-J., Davis, L. L., & Pizzagalli, D. A. (2005). The worried mind: autonomic and prefrontal activation during worrying. *Emotion*, *5*(4), 464–475. https://doi.org/10.1037/1528-3542.5.4.464

Hofmann, S. G., Schulz, S., Heering, S., Muench, F., & Bufka, L. F. (2010). Psychophysiological correlates of generalized anxiety disorder with or without comorbid depression. *International Journal of Psychophysiology*, *78*(1), 35–41. https://doi.org/10.1016/j.ijpsycho.2009.12.016

Hohl-Radke, F., Lundershausen, C., & Kaiser, W. (2010). Heart rate variability and "Antrieb" (drive, impulse): Association between a psychopathological sign and the autonomic nervous system's state in depressive patients. *Schweizer Archiv Für Neurologie Und Psychiatrie*, *161*(5), 173–177.

Holmes, S. R., & Griffin, M. J. (2001). Correlation between heart rate and the severity of motion sickness caused by optokinetic stimulation. *Journal of Psychophysiology*, *15*(1), 35–42. https://doi.org/10.1027//0269-8803.15.1.35

Hovland, A., Pallesen, S., Hammar, Å., Hansen, A. L., Thayer, J. F., Sivertsen, B., … Nordhus, I. H. (2013). Subjective sleep quality in relation to inhibition and heart rate variability in patients with panic disorder. *Journal of Affective Disorders*, *150*(1), 152–155. https://doi.org/10.1016/j.jad.2012.12.017

Hovland, A., Pallesen, S., Hammar, Å., Hansen, A. L., Thayer, J. F., Tarvainen, M. P., & Nordhus, I. H. (2012). The relationships among heart rate variability, executive functions, and clinical variables in patients with panic disorder. *International Journal of Psychophysiology*, *86*(3), 269–275. https://doi.org/10.1016/j.ijpsycho.2012.10.004

Hsu, W. C., Yen, A. M. F., Liou, H. H., Wang, H. C., & Chen, T. H. H. (2009). Prevalence and risk factors of somatic and autonomic neuropathy in prediabetic and diabetic patients. *Neuroepidemiology*, *33*(4), 344–349. https://doi.org/10.1159/000254571

Huang, W. L., Lin, Y. H., Kuo, T. B. J., Chang, L. R., Chen, Y. Z., & Yang, C. C. H. (2012). Methadone-mediated autonomic functioning of male patients with heroin dependence: The influence of borderline personality pattern. *PLoS ONE*, *7*(5), e37464. https://doi.org/10.1371/journal.pone.0037464

Hughes, J. W., & Stoney, C. M. (2000). Depressed mood is related to high-frequency heart rate variability during stressors. *Psychosomatic Medicine*, *62*(6), 796–803. https://doi.org/0033-3174/00/6206-0796

Hurst, D. F., Purdom, C. L., & Hogan, M. J. (2013). Use of paced respiration to alleviate intractable hiccups (singultus): A case report. *Applied Psychophysiology Biofeedback*, *38*(2), 157–160. https://doi.org/10.1007/s10484-013-9215-8

Ieda, M., Miyaoka, T., Wake, R., Liaury, K., Tsuchie, K., Fukushima, M., … Horiguchi, J. (2014). Evaluation of autonomic nervous system by salivary alpha-amylase level and heart rate variability in patients with schizophrenia. *European Archives of Psychiatry and Clinical Neuroscience*, *264*(1), 83–87. https://doi.org/10.1007/s00406-013-0411-6

Ikawa, M., Tabuse, H., Ueno, S., Urano, T., Sekiya, M., & Murakami, T. (2001). Effects of combination psychotropic drug treatment on heart rate variability in psychiatric patients. *Psychiatry and Clinical Neurosciences*, *55*(4), 341–345. https://doi.org/10.1046/j.1440-1819.2001.00873.x

Ingjaldsson, J. T., Laberg, J. C., & Thayer, J. F. (2003). Reduced heart rate variability in chronic alcohol abuse: Relationship with negative mood, chronic thought suppression, and compulsive drinking. *Biological Psychiatry*, *54*(12), 1427–1436. https://doi.org/10.1016/S0006-3223(02)01926-1

Ingjaldsson, J. T., Thayer, J. F., & Laberg, J. C. (2003). Craving for alcohol and pre-attentive processing of alcohol stimuli. *International Journal of Psychophysiology*, *49*(1), 29–39. https://doi.org/10.1016/S0167-8760(03)00075-8

Irwin, M. R., Olmos, L., Wang, M., Valladares, E. M., Motivala, S. J., Fong, T., … Cole, S. W. (2007). Cocaine dependence and acute cocaine induce decreases of monocyte proinflammatory cytokine expression across the diurnal period: Autonomic mechanisms. *The Journal of Pharmacology and Experimental Therapeutics*, *320*(2), 507–515. https://doi.org/10.1124/jpet.106.112797

Ishida, R., & Okada, M. (2006). Effects of a firm purpose in life on anxiety and sympathetic nervous activity caused by emotional stress: Assessment by psycho-physiological method. *Stress and Health*, *22*(4), 275–281. https://doi.org/10.1002/smi.1095

Ishizawa, T., Yoshiuchi, K., Takimoto, Y., Yamamoto, Y., & Akabayashi, A. (2008). Heart rate and blood pressure variability and baroreflex sensitivity in patients with anorexia nervosa. *Psychosomatic Medicine*, *70*(6), 695–700. https://doi.org/10.1097/PSY.0b013e31817bb090

Isowa, T., Ohira, H., & Murashima, S. (2006). Immune, endocrine and cardiovascular responses to controllable and uncontrollable acute stress. *Biological Psychology*, *71*(2), 202–213. https://doi.org/10.1016/j.biopsycho.2005.04.002

Iwanaga, M., Kobayashi, A., & Kawasaki, C. (2005). Heart rate variability with repetitive exposure to music. *Biological Psychology*, *70*(1), 61–66. https://doi.org/10.1016/j.biopsycho.2004.11.015

Jaakkola, U., Kakko, T., Juonala, M., Lehtimäki, T., Viikari, J., Jääskeläinen, A. E., … Kallio, J. (2012). Neuropeptide Y polymorphism increases the risk for asthma in overweight subjects; protection from atherosclerosis in asthmatic subjects - The cardiovascular risk in young Finns study. *Neuropeptides*, *46*(6), 321–328. https://doi.org/10.1016/j.npep.2012.09.005

Jahn, G., Oehme, A., Krems, J. F., & Gelau, C. (2005). Peripheral detection as a workload measure in driving: Effects of traffic complexity and route guidance system use in a driving study. *Transportation Research Part F*, *8*(3), 255–275. https://doi.org/10.1016/j.trf.2005.04.009

Jain, S., Siegle, G. J., Gu, C., Moore, C. G., Ivanco, L. S., Jennings, J. R., … Greenamyre, J. T. (2011). Autonomic insufficiency in pupillary and cardiovascular systems in Parkinson's disease. *Parkinsonism and Related Disorders*, *17*(2), 119–122. https://doi.org/10.1016/j.parkreldis.2010.11.005

Jandackova, V. K., Paulik, K., & Steptoe, A. (2012). The impact of unemployment on heart rate variability: The evidence from the Czech Republic. *Biological Psychology*, *91*(2), 238–244. https://doi.org/10.1016/j.biopsycho.2012.07.002

Jang, D. P., Kim, I. Y., Nam, S. W., Wiederhold, B. K., Wiederhold, M. D., & Kim, S. I. (2002). Analysis of physiological response to two virtual environments: Driving and flying simulation. *CyberPsychology & Behavior*, *5*(1), 11–18. https://doi.org/10.1089/109493102753685845

Jindal, R. D., Keshavan, M. S., Eklund, K., Stevens, A., Montrose, D. M., & Yeragani, V. K. (2009). Beat-to-beat heart rate and QT interval variability in first episode neuroleptic-naive psychosis. *Schizophrenia Research*, *113*(2–3), 176–180. https://doi.org/10.1016/j.schres.2009.06.003

Jindal, R. D., Vasko Jr., R. C., Jennings, J. R., Fasiczka, A. L., Thase, M. E., & Reynolds, C. F. (2008). Heart rate variability in depressed elderly. *American Journal of Geriatric Psychiatry*, *16*(11), 861–866. https://doi.org/10.1097/JGP.0b013e318180053d.Heart

Jochum, T., Reinhard, M., Boettger, M. K., Piater, M., & Bär, K. J. (2010). Impaired cerebral autoregulation during acute alcohol withdrawal. *Drug and Alcohol Dependence*, *110*(3), 240–246. https://doi.org/10.1016/j.drugalcdep.2010.03.007

Johnsen, B. H., Thayer, J. F., Laberg, J. C., Wormnes, B., Raadal, M., Skaret, E., … Berg, E. (2003). Attentional and physiological characteristics of patients with dental anxiety. *Journal of Anxiety Disorders*, *17*(1), 75–87. https://doi.org/10.1016/S0887-6185(02)00178-0

Jönsson, P., & Hansson-Sandsten, M. (2008). Respiratory sinus arrhythmia in response to fear-relevant and fear-irrelevant stimuli. *Scandinavian Journal of Psychology*, *49*(2), 123–131. https://doi.org/10.1111/j.1467-9450.2008.00638.x

Jönsson, P., & Sonnby-Borgström, M. (2003). The effects of pictures of emotional faces on tonic and phasic autonomic cardiac control in women and men. *Biological Psychology*, *62*(2), 157–173. https://doi.org/10.1016/S0301-0511(02)00114-X

Jönsson, P., Wallergård, M., Österberg, K., Hansen, Å. M., Johansson, G., & Karlson, B. (2010). Cardiovascular and cortisol reactivity and habituation to a virtual reality version of the Trier Social Stress Test: A pilot study. *Psychoneuroendocrinology*, *35*(9), 1397–1403. https://doi.org/10.1016/j.psyneuen.2010.04.003

Joosen, M., Frings-Dresen, M. H. W., & Sluiter, J. K. (2011). Process and outcome evaluation of vocational rehabilitation interventions in patients with prolonged fatigue complaints. *International Journal of Behavioral Medicine*, *18*(2), 160–171. https://doi.org/10.1007/s12529-010-9099-4

Joosen, M., Frings-Dresen, M. H. W., & Sluiter, J. K. (2013). Long-term outcomes following vocational rehabilitation treatments in patients with prolonged fatigue. *International Journal of Behavioral Medicine*, *20*(1), 42–51. https://doi.org/10.1007/s12529-011-9208-z

JØrgensen, M. M., & Zachariae, R. (2006). Repressive coping style and autonomic reactions to two experimental stressors in healthy men and women. *Scandinavian Journal of Psychology*, *47*(2), 137–148. https://doi.org/10.1111/j.1467-9450.2006.00501.x

Kaber, D. B., Perry, C. M., Segall, N., & Sheik-Nainar, M. A. (2007). Workload state classification with automation during simulated air traffic control. *The International Journal of Aviation Psychology*, *17*(4), 371–390. https://doi.org/10.1080/10508410701527860

Kaida, K., Akerstedt, T., Kecklund, G., Nilsson, J. P., & Axelsson, J. (2007). The effects of asking for verbal ratings of sleepiness on sleepiness and its masking effects on performance. *Clinical Neurophysiology*, *118*(6), 1324–1331. https://doi.org/10.1016/j.clinph.2007.03.004

Kanaley, J. A., Goulopoulou, S., Franklin, R. M., Baynard, T., Holmstrup, M. E., Carhart, R., … Fernhall, B. (2009). Plasticity of heart rate signalling and complexity with exercise training in obese individuals with and without type 2 diabetes. *International Journal of Obesity*, *33*(10), 1198–1206. https://doi.org/10.1038/ijo.2009.145

Kaplan, U., & Epstein, G. N. (2011). Psychophysiological coherence as a function of mental imagery practice. *Imagination, Cognition and Personality*, *31*(4), 297–312. https://doi.org/10.2190/IC.31.4.d

Karavidas, M. K., Lehrer, P. M., Vaschillo, E., Vaschillo, B., Marin, H., Buyske, S., … Hassett, A. (2007). Preliminary results of an open label study of heart rate variability biofeedback for the treatment of major depression. *Applied Psychophysiology Biofeedback*, *32*(1), 19–30. https://doi.org/10.1007/s10484-006-9029-z

Katz-Leurer, M., & Shochina, M. (2005). Heart Rate Variability (HRV) parameters correlate with motor impairment and aerobic capacity in stroke patients. *NeuroRehabilitation*, *20*(2), 91–95.

Katz-Leurer, M., & Shochina, M. (2007). The influence of autonomic impairment on aerobic exercise outcome in stroke patients. *NeuroRehabilitation*, *22*(4), 267–272.

Kaufmann, T., Vögele, C., Sütterlin, S., Lukito, S., & Kübler, A. (2012). Effects of resting heart rate variability on performance in the P300 brain-computer interface. *International Journal of Psychophysiology*, *83*(3), 336–341. https://doi.org/10.1016/j.ijpsycho.2011.11.018

Kavanagh, J. J., Grant, G. D., & Anoopkumar-Dukie, S. (2012). Low dosage promethazine and loratadine negatively affect neuromotor function. *Clinical Neurophysiology*, *123*(4), 780–786. https://doi.org/10.1016/j.clinph.2011.07.046

Kawano, A., Tanaka, Y., Ishitobi, Y., Maruyama, Y., Ando, T., Inoue, A., … Akiyoshi, J. (2013). Salivary alpha-amylase and cortisol responsiveness following electrical stimulation stress in obsessive–compulsive disorder patients. *Psychiatry Research*, *209*(1), 85–90. https://doi.org/10.1016/j.psychres.2012.11.010

Keary, T. A., Hughes, J. W., & Palmieri, P. A. (2009). Women with posttraumatic stress disorder have larger decreases in heart rate variability during stress tasks. *International Journal of Psychophysiology*, *73*(3), 257–264. https://doi.org/10.1016/j.ijpsycho.2009.04.003

Keller, J., Bless, H., Blomann, F., & Kleinböhl, D. (2011). Physiological aspects of flow experiences: Skills-demand-compatibility effects on heart rate variability and salivary cortisol. *Journal of Experimental Social Psychology*, *47*(4), 849–852. https://doi.org/10.1016/j.jesp.2011.02.004

Kemp, A. H., Quintana, D. S., Felmingham, K. L., Matthews, S., & Jelinek, H. F. (2012). Depression, comorbid anxiety disorders, and heart rate variability in physically healthy, unmedicated patients: Implications for cardiovascular risk. *PLoS ONE*, *7*(2), e30777. https://doi.org/10.1371/journal.pone.0030777

Kemp, A. H., Quintana, D. S., Kuhnert, R. L., Griffiths, K., Hickie, I. B., & Guastella, A. J. (2012). Oxytocin increases heart rate variability in humans at rest: Implications for social approach-related motivation and capacity for social engagement. *PLoS ONE*, *7*(8), e44014. https://doi.org/10.1371/journal.pone.0044014

Keren, O., Yupatov, S., Radai, M. M., Elad-Yarum, R., Faraggi, D., Abboud, S., … Groswasser, Z. (2005). Heart rate variability (HRV) of patients with traumatic brain injury (TBI) during the post-insult sub-acute period. *Brain Injury*, *19*(8), 605–611. https://doi.org/10.1080/02699050400024946

Kettunen, J., & Keltikangas-Järvinen, L. (2001). Intraindividual analysis of instantaneous heart rate variability. *Psychophysiology*, *38*(4), 659–668. https://doi.org/10.1017/S0048577201991632

Key, B. L., Campbell, T. S., Bacon, S. L., & Gerin, W. (2008). The influence of trait and state rumination on cardiovascular recovery from a negative emotional stressor. *Journal of Behavioral Medicine*, *31*(3), 237–248. https://doi.org/10.1007/s10865-008-9152-9

Kikuchi, M., Hanaoka, A., Kidani, T., Remijn, G. B., Minabe, Y., Munesue, T., & Koshino, Y. (2009). Heart rate variability in drug-naïve patients with panic disorder and major depressive disorder. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *33*(8), 1474–1478. https://doi.org/10.1016/j.pnpbp.2009.08.002

Kim, D. H., Lipsitz, L. A., Ferrucci, L., Varadhan, R., Guralnik, J. M., Carlson, M. C., … Chaves, P. H. M. (2006). Association between reduced heart rate variability and cognitive impairment in older disabled women in the community: Women's health and aging study I. *Journal of the American Geriatrics Society*, *54*(11), 1751–1757. https://doi.org/10.1111/j.1532-5415.2006.00940.x

Kim, J. H., Ann, J.-H., & Lee, J. (2011). Relationship between heart rate variability and the severity of psychotic symptoms in schizophrenia. *Acta Neuropsychiatrica*, *23*(4), 161–166. https://doi.org/10.1111/j.1601-5215.2011.00549.x

Kim, J. H., Yi, S. H., Yoo, C. S., Yang, S. A., Yoon, S. C., Lee, K. Y., … Kim, Y. S. (2004). Heart rate dynamics and their relationship to psychotic symptom severity in clozapine-treated schizophrenic subjects. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *28*(2), 371–378. https://doi.org/10.1016/j.pnpbp.2003.11.007

Kim, K. S., & Nam, H. J. (2010). Autonomic nervous function in final year Oriental medical students in Korea: Influence of gender, age and academic performance. *Stress and Health*, *26*(5), 430–436. https://doi.org/10.1002/smi.1316

Kim, S.-J., Kwon, O.-Y., & Yi, C.-H. (2009). Effects of manual lymph drainage on cardiac autonomic tone in healthy subjects. *The International Journal of Neuroscience*, *119*(8), 1105–1117. https://doi.org/10.1080/00207450902834884

Kimura, K., Ozeki, M., Juneja, L. R., & Ohira, H. (2007). l-Theanine reduces psychological and physiological stress responses. *Biological Psychology*, *74*(1), 39–45. https://doi.org/10.1016/j.biopsycho.2006.06.006

Kiselev, A. R., Gridnev, V. I., Posnenkova, O. M., Strunina, A. N., Shvarts, V. A., & Dovgalevskii, Y. P. (2008). Changes in the power of the low- and high-frequency bands of the heart rate variability spectrum in coronary heart disease patients with different severities of coronary atherosclerosis in the course of load tests. *Human Physiology*, *34*(3), 312–318. https://doi.org/10.1134/S0362119708030079

Kleen, M., & Reitsma, B. (2011). Appliance of heart rate variability biofeedback in acceptance and commitment therapy: A pilot study. *Journal of Neurotherapy*, *15*(2), 170–181. https://doi.org/10.1080/10874208.2011.570695

Knapp-Kline, K., & Kline, J. P. (2005). Heart rate, heart rate variability, and heartbeat detection with the method of constant stimuli: Slow and steady wins the race. *Biological Psychology*, *69*(3), 387–396. https://doi.org/10.1016/j.biopsycho.2004.09.002

Knepp, M. M., & Friedman, B. H. (2008). Cardiovascular activity during laboratory tasks in women with high and low worry. *Biological Psychology*, *79*(3), 287–293. https://doi.org/10.1016/j.biopsycho.2008.07.002

Kocer, A., Karakaya, O., Barutcu, I., Batukan Esen, O., Kargın, R., & Mayda Domac, F. (2006). Assesment of P wave duration and dispersion in Parkinson's disease. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *30*(4), 718–723. https://doi.org/10.1016/j.pnpbp.2006.02.011

Koelsch, S., Remppis, A., Sammler, D., Jentschke, S., Mietchen, D., Fritz, T., … Siebel, W. A. (2007). A cardiac signature of emotionality. *European Journal of Neuroscience*, *26*(11), 3328–3338. https://doi.org/10.1111/j.1460-9568.2007.05889.x

Kofman, O., Meiran, N., Greenberg, E., Balas, M., & Cohen, H. (2006). Enhanced performance on executive functions associated with examination stress: Evidence from task-switching and Stroop paradigms. *Cognition and Emotion*, *20*(5), 577–595. https://doi.org/10.1080/02699930500270913

Kohsaka, M., Kohsaka, S., Fukuda, N., Honma, H., Sakakibara, S., Kawai, I., … Kobayashi, R. (2001). Effects of bright light exposure on heart rate variability during sleep in young women. *Psychiatry and Clinical Neurosciences*, *55*(3), 283–284. https://doi.org/10.1046/j.1440-1819.2001.00861.x

Kop, W. J., Synowski, S. J., Newell, M. E., Schmidt, L. A., Waldstein, S. R., & Fox, N. A. (2011). Autonomic nervous system reactivity to positive and negative mood induction: The role of acute psychological responses and frontal electrocortical activity. *Biological Psychology*, *86*(3), 230–238. https://doi.org/10.1016/j.biopsycho.2010.12.003

Kop, W. J., Weinstein, A. A., Deuster, P. A., Whittaker, K. S., & Tracy, R. P. (2008). Inflammatory markers and negative mood symptoms following exercise withdrawal. *Brain, Behavior, and Immunity*, *22*(8), 1190–1196. https://doi.org/10.1016/j.bbi.2008.05.011

Koschke, M., Boettger, M. K., MacHoldt, C., Schulz, S., Yeragani, V. K., Voss, A., & Bär, K. J. (2010). Increased QT variability in patients with anorexia nervosa-An indicator for increased cardiac mortality? *International Journal of Eating Disorders*, *43*(8), 743–750. https://doi.org/10.1002/eat.20765

Koschke, M., Boettger, M. K., Schulz, S., Berger, S., Terhaar, J., Voss, A., … Bär, K. J. (2009). Autonomy of autonomic dysfunction in major depression. *Psychosomatic Medicine*, *71*(8), 852–860. https://doi.org/10.1097/PSY.0b013e3181b8bb7a

Krantz, G., Kreutz, G., Ericson, M., & Theorell, T. (2011). Bodily movements influence heart rate variability (HRV) responses to isolated melodic intervals. *Music and Medicine*, *3*(2), 108–113. https://doi.org/10.1177/1943862110387612

Kreibig, S. D., Wilhelm, F. H., Roth, W. T., & Gross, J. J. (2007). Cardiovascular, electrodermal, and respiratory response patterns to fear- and sadness-inducing films. *Psychophysiology*, *44*(5), 787–806. https://doi.org/10.1111/j.1469-8986.2007.00550.x

Krygier, J. R., Heathers, J. A. J., Shahrestani, S., Abbott, M., Gross, J. J., & Kemp, A. H. (2013). Mindfulness meditation, well-being, and heart rate variability: A preliminary investigation into the impact of intensive vipassana meditation. *International Journal of Psychophysiology*, *89*(3), 305–313. https://doi.org/10.1016/j.ijpsycho.2013.06.017

Kubota, Y., Sato, W., Toichi, M., Murai, T., Okada, T., Hayashi, A., & Sengoku, A. (2001). Frontal midline theta rhythm is correlated with cardiac autonomic activities during the performance of an attention demanding meditation procedure. *Cognitive Brain Research*, *11*(2), 281–287. https://doi.org/10.1016/S0926-6410(00)00086-0

Kunz, V. C., Borges, E. N., Coelho, R. C., Gubolino, L. A., Martins, L. E. B., & Silva, E. (2012). Linear and nonlinear analysis of heart rate variability in healthy subjects and after acute myocardial infarction in patients. *Brazilian Journal of Medical and Biological Research*, *45*(5), 450–458. https://doi.org/10.1590/S0100-879X2012007500025

Kunz-Ebrecht, S. R., Mohamed-Ali, V., Feldman, P. J., Kirschbaum, C., & Steptoe, A. (2003). Cortisol responses to mild psychological stress are inversely associated with proinflammatory cytokines. *Brain, Behavior, and Immunity*, *17*(5), 373–383. https://doi.org/10.1016/S0889-1591(03)00029-1

Laaksonen, S. M., Röyttä, M., Jääskeläinen, S. K., Kantola, I., Penttinen, M., & Falck, B. (2008). Neuropathic symptoms and findings in women with Fabry disease. *Clinical Neurophysiology*, *119*(6), 1365–1372. https://doi.org/10.1016/j.clinph.2008.02.004

Laborde, S., Brüll, A., Weber, J., & Anders, L. S. (2011). Trait emotional intelligence in sports: A protective role against stress through heart rate variability? *Personality and Individual Differences*, *51*(1), 23–27. https://doi.org/10.1016/j.paid.2011.03.003

Lache, B., Meyer, T., & Herrmann-Lingen, C. (2007). Social support predicts hemodynamic recovery from mental stress in patients with implanted defibrillators. *Journal of Psychosomatic Research*, *63*(5), 515–523. https://doi.org/10.1016/j.jpsychores.2007.06.024

Lackner, H. K., Goswami, N., Hinghofer-Szalkay, H., Papousek, I., Scharfetter, H., Furlan, R., & Schwaberger, G. (2010). Effects of stimuli on cardiovascular reactivity occurring at regular intervals during mental stress. *Journal of Psychophysiology*, *24*(1), 48–60. https://doi.org/10.1027/0269-8803/a000006

Lackner, H. K., Papousek, I., Batzel, J. J., Roessler, A., Scharfetter, H., & Hinghofer-Szalkay, H. (2011). Phase synchronization of hemodynamic variables and respiration during mental challenge. *International Journal of Psychophysiology*, *79*(3), 401–409. https://doi.org/10.1016/j.ijpsycho.2011.01.001

Lackner, H. K., Weiss, E. M., Hinghofer-Szalkay, H., & Papousek, I. (2013). Cardiovascular effects of acute positive emotional arousal. *Applied Psychophysiology and Biofeedback*, *39*(1), 9–18. https://doi.org/10.1007/s10484-013-9235-4

Lackschewitz, H., Hüther, G., & Kröner-Herwig, B. (2008). Physiological and psychological stress responses in adults with attention-deficit/hyperactivity disorder (ADHD). *Psychoneuroendocrinology*, *33*(5), 612–624. https://doi.org/10.1016/j.psyneuen.2008.01.016

Lai, F.-C., Chang, W.-L., & Jeng, C. (2012). The relationship between physical activity and heart rate variability in orthotopic heart transplant recipients. *Journal of Clinical Nursing*, *21*(21–22), 3235–3243. https://doi.org/10.1111/j.1365-2702.2012.04070.x

Lai, H. L., Li, Y. M., & Lee, L. H. (2012). Effects of music intervention with nursing presence and recorded music on psycho-physiological indices of cancer patient caregivers. *Journal of Clinical Nursing*, *21*(5–6), 745–756. https://doi.org/10.1111/j.1365-2702.2011.03916.x

Lane, R. D., McRae, K., Reiman, E. M., Chen, K., Ahern, G. L., & Thayer, J. F. (2009). Neural correlates of heart rate variability during emotion. *NeuroImage*, *44*(1), 213–222. https://doi.org/10.1016/j.neuroimage.2008.07.056

Lanotte, M., Lopiano, L., Torre, E., Bergamasco, B., Colloca, L., & Benedetti, F. (2005). Expectation enhances autonomic responses to stimulation of the human subthalamic limbic region. *Brain, Behavior, and Immunity*, *19*(6), 500–509. https://doi.org/10.1016/j.bbi.2005.06.004

Larue, G. S., Rakotonirainy, A., & Pettitt, A. N. (2011). Driving performance impairments due to hypovigilance on monotonous roads. *Accident Analysis and Prevention*, *43*(6), 2037–2046. https://doi.org/10.1016/j.aap.2011.05.023

Lau, W.-C., Choi, K.-S., & Chung, W.-Y. (2010). A virtual psychiatric ward for orientating patients admitted for the first time. *Cyberpsychology, Behavior, and Social Networking*, *13*(6), 637–648. https://doi.org/10.1089/cyber.2009.0107

Lee, J., Park, B. J., Tsunetsugu, Y., Ohira, T., Kagawa, T., & Miyazaki, Y. (2011). Effect of forest bathing on physiological and psychological responses in young Japanese male subjects. *Public Health*, *125*(2), 93–100. https://doi.org/10.1016/j.puhe.2010.09.005

Lee, J. S., Kim, B., Hong, Y., & Joo, Y. H. (2012). Heart rate variability in the subsyndromal depressive phase of bipolar disorder. *Psychiatry and Clinical Neurosciences*, *66*(4), 361–366. https://doi.org/10.1111/j.1440-1819.2012.02335.x

Lee, K. C., Chao, Y. H., Yiin, J. J., Chiang, P. Y., & Chao, Y. F. (2011). Effectiveness of different music-playing devices for reducing preoperative anxiety: A clinical control study. *International Journal of Nursing Studies*, *48*(10), 1180–1187. https://doi.org/10.1016/j.ijnurstu.2011.04.001

Lee, M. S., Kim, H.-J., Song, J., & Park, K.-W. (2004). Effects of multifunctional fabrics on cardiac autonomic tone and psychological state. *International Journal of Neuroscience*, *114*(8), 923–931. https://doi.org/10.1080/00207450490461297

Lee, M. S., Kim, M. K., & Lee, Y.-H. (2005). Effects of Qi-therapy (external qigong) on cardiac autonomic tone: A randomized placebo controlled study. *International Journal of Neuroscience*, *115*(9), 1345–1350. https://doi.org/10.1080/00207450590934543

Lee, M. S., Shin, B.-C., Rim, Y.-H., & Woo, W. H. (2005). Effects of korean traditional herbal remedy on heart rate variability: Linear and nonlinear analysis. *International Journal of Neuroscience*, *115*(3), 393–403. https://doi.org/10.1080/00207450590521091

Lehrer, P. M., Karavidas, M. K., Lu, S.-E., Coyle, S. M., Oikawa, L. O., MacOr, M., … Lowry, S. F. (2010). Voluntarily produced increases in heart rate variability modulate autonomic effects of endotoxin induced systemic inflammation: An exploratory study. *Applied Psychophysiology Biofeedback*, *35*(4), 303–315. https://doi.org/10.1007/s10484-010-9139-5

Lehrer, P. M., Karavidas, M. K., Lu, S.-E., Vaschillo, E., Vaschillo, B., & Cheng, A. (2010). Cardiac data increase association between self-report and both expert ratings of task load and task performance in flight simulator tasks: An exploratory study. *International Journal of Psychophysiology*, *76*(2), 80–87. https://doi.org/10.1016/j.ijpsycho.2010.02.006

Lehrer, P. M., Vaschillo, E., Trost, Z., & France, C. R. (2009). Effects of rhythmical muscle tension at 0.1 Hz on cardiovascular resonance and the baroreflex. *Biological Psychology*, *81*(1), 24–30. https://doi.org/10.1016/j.biopsycho.2009.01.003

Lehrer, P. M., Vaschillo, E., Vaschillo, B., Lu, S.-E., Eckberg, D. L., Edelberg, R., … Hamer, R. M. (2003). Heart rate variability biofeedback increases baroreflex gain and peak expiratory flow. *Psychosomatic Medicine*, *65*(5), 796–805. https://doi.org/10.1097/01.PSY.0000089200.81962.19

León, I., Hernández, J. A., Rodríguez, S., & Vila, J. (2009). When head is tempered by heart: Heart rate variability modulates perception of other-blame reducing anger. *Motivation and Emotion*, *33*(1), 1–9. https://doi.org/10.1007/s11031-008-9112-2

Lévesque, K., Moskowitz, D. S., Tardif, J. C., Dupuis, G., & D'Antono, B. (2010). Physiological stress responses in defensive individuals: Age and sex matter. *Psychophysiology*, *47*(2), 332–341. https://doi.org/10.1111/j.1469-8986.2009.00943.x

Lewis, G., Furman, S. A., McCool, M. F., & Porges, S. W. (2012). Statistical strategies to quantify respiratory sinus arrhythmia: Are commonly used metrics equivalent? *Biological Psychology*, *89*(2), 349–364. https://doi.org/10.1016/j.biopsycho.2011.11.009

Lewis, M. J., & Phillips, J. E. (2012). Older people's cardiac responses as indicators of stress in familiar and unfamiliar environments. *Psychophysiology*, *49*(4), 478–483. https://doi.org/10.1111/j.1469-8986.2011.01321.x

Lewis-Evans, B., de Waard, D., Jolij, J., & Brookhuis, K. A. (2012). What you may not see might slow you down anyway: Masked images and driving. *PLoS ONE*, *7*(1), e29857. https://doi.org/10.1371/journal.pone.0029857

Mueck-Weymann, M., Moesler, T., Joraschky, P., Rebensburg, M., & Agelink, M. W. (2002). Depression modulates autonomic cardiac control: A physiopsychological pathway linking depression and mortality? *German Journal of Psychiatry*, *5*(3), 67–69.

Mujica-Parodi, L. R., Renelique, R., & Taylor, M. (2009). Higher body fat percentage is associated with increased cortisol reactivity and impaired cognitive resilience in response to acute emotional stress. *International Journal of Obesity*, *33*(1), 157–165. https://doi.org/10.1038/ijo.2008.218

Mukherjee, S., Yadav, R., Yung, I., Zajdel, D. P., & Oken, B. S. (2011). Sensitivity to mental effort and test-retest reliability of heart rate variability measures in healthy seniors. *Clinical Neurophysiology*, *122*(10), 2059–2066. https://doi.org/10.1016/j.clinph.2011.02.032

Mun, E. Y., von Eye, A., Bates, M. E., & Vaschillo, E. (2008). Finding groups using model-based cluster analysis: heterogeneous emotional self-regulatory processes and heavy alcohol use risk. *Developmental Psychology*, *44*(2), 481–495. https://doi.org/10.1037/0012-1649.44.2.481

Murata, T., Takahashi, T., Hamada, T., Omori, M., Kosaka, H., Yoshida, H., & Wada, Y. (2004). Individual trait anxiety levels characterizing the properties of Zen meditation. *Neuropsychobiology*, *50*(2), 189–194. https://doi.org/10.1159/000079113

Murray, N. P., & Russoniello, C. V. (2012). Acute physical activity on cognitive function: A heart rate variability examination. *Applied Psychophysiology and Biofeedback*, *37*(4), 219–227. https://doi.org/10.1007/s10484-012-9196-z

Mussgay, L., & Rüddel, H. (2004). Autonomic dysfunctions in patients with anxiety throughout therapy. *Journal of Psychophysiology*, *18*(1), 27–37. https://doi.org/10.1027/0269-8803.18.1.27

Nahshoni, E., Aizenberg, D., Sigler, M., Strasberg, B., Zalsman, G., Imbar, S., … Weizman, A. (2004). Heart rate variability increases in elderly depressed patients who respond to electroconvulsive therapy. *Journal of Psychosomatic Research*, *56*(1), 89–94. https://doi.org/10.1016/S0022-3999(03)00037-0

Nahshoni, E., Aizenberg, D., Sigler, M., Zalsman, G., Strasberg, B., Imbar, S., & Weizman, A. (2001). Heart rate variability in elderly patients before and after electroconvulsive therapy. *The American Journal of Geriatric Psychiatry*, *9*(3), 255–260. https://doi.org/10.1097/00019442-200108000-00009

Nahshoni, E., Aravot, D., Aizenberg, D., Sigler, M., Zalsman, G., Strasberg, B., … Weizman, A. (2004). Heart rate variability in patients with major depression. *Psychosomatics*, *45*(2), 129–134. https://doi.org/10.1176/appi.psy.45.2.129

Nakahara, H., Furuya, S., Francis, P. R., & Kinoshita, H. (2010). Psycho-physiological responses to expressive piano performance. *International Journal of Psychophysiology*, *75*(3), 268–276. https://doi.org/10.1016/j.ijpsycho.2009.12.008

Nakahara, H., Furuya, S., Masuko, T., Francis, P. R., & Kinoshita, H. (2011). Performing music can induce greater modulation of emotion-related psychophysiological responses than listening to music. *International Journal of Psychophysiology*, *81*(3), 152–158. https://doi.org/10.1016/j.ijpsycho.2011.06.003

Napadow, V., Dhond, R., Conti, G., Makris, N., Brown, E. N., & Barbieri, R. (2008). Brain correlates of autonomic modulation: Combining heart rate variability with fMRI. *NeuroImage*, *42*(1), 169–177. https://doi.org/10.1016/j.neuroimage.2008.04.238

Narita, K., Murata, T., Hamada, T., Takahashi, T., Omori, M., Suganuma, N., … Wada, Y. (2007). Interactions among higher trait anxiety, sympathetic activity, and endothelial function in the elderly. *Journal of Psychiatric Research*, *41*(5), 418–427. https://doi.org/10.1016/j.jpsychires.2006.01.003

Narita, K., Murata, T., Takahashi, T., Hamada, T., Kosaka, H., Yoshida, H., & Wada, Y. (2007). The association between anger-related personality trait and cardiac autonomic response abnormalities in elderly subjects. *European Archives of Psychiatry and Clinical Neuroscience*, *257*(6), 325–329. https://doi.org/10.1007/s00406-007-0724-4

Nava, E., Landau, D., Brody, S., Linder, L., & Schächinger, H. (2004). Mental relaxation improves long-term incidental visual memory. *Neurobiology of Learning and Memory*, *81*(3), 167–171. https://doi.org/10.1016/j.nlm.2004.02.001

Nederkoorn, C., Smulders, F. T., & Jansen, A. (2000). Cephalic phase responses, craving and food intake in normal subjects. *Appetite*, *35*(1), 45–55. https://doi.org/10.1006/appe.2000.0328

Neumann, D. L., & Thomas, P. (2009). The relationship between skill level and patterns in cardiac and respiratory activity during golf putting. *International Journal of Psychophysiology*, *72*(3), 276–282. https://doi.org/10.1016/j.ijpsycho.2009.01.001

Neumann, D. L., & Thomas, P. (2011). Cardiac and respiratory activity and golf putting performance under attentional focus instructions. *Psychology of Sport and Exercise*, *12*(4), 451–459. https://doi.org/10.1016/j.psychsport.2011.02.002

Neumann, S. A., Brown, S. M., Ferrell, R. E., Flory, J. D., Manuck, S. B., & Hariri, A. R. (2006). Human Choline Transporter Gene Variation Is Associated with Corticolimbic Reactivity and Autonomic-Cholinergic Function. *Biological Psychiatry*, *60*(10), 1155–1162. https://doi.org/10.1016/j.biopsych.2006.03.059

Neumann, S. A., Lawrence, E. C., Jennings, J. R., Ferrell, R. E., & Manuck, S. B. (2005). Heart rate variability is associated with polymorphic variation in the choline transporter gene. *Psychosomatic Medicine*, *67*(2), 168–171. https://doi.org/10.1097/01.psy.0000155671.90861.c2

Neumann, S. A., Sollers, J. J., Thayer, J. F., & Waldstein, S. R. (2004). Alexithymia predicts attenuated autonomic reactivity, but prolonged recovery to anger recall in young women. *International Journal of Psychophysiology*, *53*(3), 183–195. https://doi.org/10.1016/j.ijpsycho.2004.03.008

Neumann, S. A., Tingley, W. G., Conklin, B. R., Shrader, C. J., Peet, E., Muldoon, M. F., … Manuck, S. B. (2009). AKAP10 (I646V) functional polymorphism predicts heart rate and heart rate variability in apparently healthy, middle-aged European-Americans. *Psychophysiology*, *46*(3), 466–472. https://doi.org/10.1111/j.1469-8986.2009.00802.x

Nickel, P., & Nachreiner, F. (2003). Sensitivity and diagnosticity of the 0.1-Hz component of heart rate variability as an indicator of mental workload. *Human Factors*, *45*(4), 575–590. https://doi.org/10.1518/hfes.45.4.575.27094

Nikolova, R., Aleksiev, L., & Vukov, M. (2007). Psychophysiological assessment of stress and screening of health risk in peacekeeping operations. *Military Medicine*, *172*(1), 44–48. https://doi.org/17274265

Nilsen, K. B., Tronvik, E., Sand, T., Gravdahl, G. B., & Stovner, L. J. (2009). Increased baroreflex sensitivity and heart rate variability in migraine patients. *Acta Neurologica Scandinavica*, *120*(6), 418–423. https://doi.org/10.1111/j.1600-0404.2009.01173.x

Norman, G. J., Cacioppo, J. T., Morris, J. S., Malarkey, W. B., Berntson, G. G., & DeVries, A. C. (2011). Oxytocin increases autonomic cardiac control: Moderation by loneliness. *Biological Psychology*, *86*(3), 174–180. https://doi.org/10.1016/j.biopsycho.2010.11.006

Norte, C. E., Souza, G. G. L., Vilete, L., Marques-Portella, C., Coutinho, E. S. F., Figueira, I., & Volchan, E. (2013). They know their trauma by heart: An assessment of psychophysiological failure to recover in PTSD. *Journal of Affective Disorders*, *150*(1), 136–141. https://doi.org/10.1016/j.jad.2012.11.039

Nugent, A. C., Bain, E. E., Thayer, J. F., Sollers, J. J., & Drevets, W. C. (2011). Sex differences in the neural correlates of autonomic arousal: A pilot PET study. *International Journal of Psychophysiology*, *80*(3), 182–191. https://doi.org/10.1016/j.ijpsycho.2011.03.001

Nugent, A. C., Bain, E. E., Thayer, J. F., Sollers, J. J., & Drevets, W. C. (2011). Heart rate variability during motor and cognitive tasks in females with major depressive disorder. *Psychiatry Research: Neuroimaging*, *191*(1), 1–8. https://doi.org/10.1016/j.pscychresns.2010.08.013

Nyklíček, I., Mommersteeg, P., Van Beugen, S., Ramakers, C., & Van Boxtel, G. (2013). Mindfulness-based stress reduction and physiological activity during acute stress: A randomized controlled trial. *Health Psychology*, *32*(10), 1110–1113. https://doi.org/http://dx.doi.org/10.1037/a0032200

O'Connor, M.-F., Allen, J. J. B., & Kaszniak, A. W. (2002). Autonomic and emotion regulation in bereavement and depression. *Journal of Psychosomatic Research*, *52*(4), 183–185. https://doi.org/10.1016/S0022-3999(02)00292-1

Ode, S., Hilmert, C. J., Zielke, D. J., & Robinson, M. D. (2010). Neuroticism's importance in understanding the daily life correlates of heart rate variability. *Emotion*, *10*(4), 536–543. https://doi.org/10.1037/a0018698

O'Donnell, K., Brydon, L., Wright, C. E., & Steptoe, A. (2008). Self-esteem levels and cardiovascular and inflammatory responses to acute stress. *Brain, Behavior, and Immunity*, *22*(8), 1241–1247. https://doi.org/10.1016/j.bbi.2008.06.012

Ohira, H., Matsunaga, M., Osumi, T., Fukuyama, S., Shinoda, J., Yamada, J., & Gidron, Y. (2013). Vagal nerve activity as a moderator of brain-immune relationships. *Journal of Neuroimmunology*, *260*(1–2), 28–36. https://doi.org/10.1016/j.jneuroim.2013.04.011

Ohira, T., Diez Roux, A. V, Prineas, R. J., Kizilbash, M. a, Carnethon, M. R., & Folsom, A. R. (2008). Associations of psychosocial factors with heart rate and its short-term variability: multi-ethnic study of atherosclerosis. *Psychosomatic Medicine*, *70*(2), 141–146. https://doi.org/10.1097/PSY.0b013e318160686a

Okada, T., Toichi, M., & Sakihama, M. (2003). Influences of an anticholinergic antiparkinsonian drug, parkinsonism, and psychotic symptoms on cardiac autonomic function in schizophrenia. *Journal of Clinical Psychopharmacology*, *23*(5), 441–447. https://doi.org/10.1097/01.jcp.0000088901.24613.b8

Olbrich, S., Sander, C., Matschinger, H., Mergl, R., Trenner, M., Schönknecht, P., & Hegerl, U. (2011). Brain and body: Associations between EEG-vigilance and the autonomous nervous system activity during rest. *Journal of Psychophysiology*, *25*(4), 190–200. https://doi.org/10.1027/0269-8803/a000061

Olsson, E. M. G., Roth, W. T., & Melin, L. (2010). Psychophysiological characteristics of women suffering from stress-related fatigue. *Stress and Health*, *26*(2), 113–126. https://doi.org/10.1002/smi.1271

Olsson, E. M. G., & von Schéele, B. (2011). Relaxing on a bed of nails: An exploratory study of the effects on the autonomic, cardiovascular, and respiratory systems, and saliva cortisol. *Journal of Alternative and Complementary Medicine*, *17*(1), 5–12. https://doi.org/10.1089/acm.2010.0135

Olsson, E. M. G., von Schéele, B., & Theorell, T. (2013). Heart Rate Variability During Choral Singing. *Music and Medicine*, *5*(1), 52–59. https://doi.org/10.1177/1943862112471399

Ossewaarde, L., Qin, S., Van Marle, H. J. F., van Wingen, G. A., Fernández, G., & Hermans, E. J. (2011). Stress-induced reduction in reward-related prefrontal cortex function. *NeuroImage*, *55*(1), 345–352. https://doi.org/10.1016/j.neuroimage.2010.11.068

Ottaviani, C., Mancini, F., Petrocchi, N., Medea, B., & Couyoumdjian, A. (2013). Autonomic correlates of physical and moral disgust. *International Journal of Psychophysiology*, *89*(1), 57–62. https://doi.org/10.1016/j.ijpsycho.2013.05.003

Ottaviani, C., & Shapiro, D. (2011). Do we need a stressor to be stressed? Insights from cardiac regulation. *Japanese Psychological Research*, *53*(2), 155–162. https://doi.org/10.1111/j.1468-5884.2011.00462.x

Ottaviani, C., Shapiro, D., & Couyoumdjian, A. (2013). Flexibility as the key for somatic health: From mind wandering to perseverative cognition. *Biological Psychology*, *94*(1), 38–43. https://doi.org/10.1016/j.biopsycho.2013.05.003

Ottaviani, C., Shapiro, D., Davydov, D. M., Goldstein, I. B., & Mills, P. J. (2009). The autonomic phenotype of rumination. *International Journal of Psychophysiology*, *72*(3), 267–275. https://doi.org/10.1016/j.ijpsycho.2008.12.014

Oveis, C., Cohen, A. B., Gruber, J., Shiota, M. N., Haidt, J., & Keltner, D. (2009). Resting respiratory sinus arrhythmia is associated with tonic positive emotionality. *Emotion*, *9*(2), 265–270. https://doi.org/10.1037/a0015383

Overhaus, S., Rüddel, H., Curio, I., Mussgay, L., & Scholz, O. B. (2003). Biofeedback of baroreflex sensitivity in patients with mild essential hypertension. *International Journal of Behavioral Medicine*, *10*(1), 66–79.

Owen, N., & Steptoe, A. (2003). Natural killer cell and proinflammatory cytokine responses to mental stress: Associations with heart rate and heart rate variability. *Biological Psychology*, *63*(2), 101–115. https://doi.org/10.1016/S0301-0511(03)00023-1

Pantoni, C. B. F., Di Thommazo, L., Mendes, R. G., Catai, A. M., Luzzi, S., Amaral Neto, O., & Borghi-Silva, A. (2011). Effects of different levels of positive airway pressure on breathing pattern and heart rate variability after coronary artery bypass grafting surgery. *Brazilian Journal of Medical and Biological Research*, *44*(1), 38–45. https://doi.org/10.1590/S0100-879X2010007500129

Papousek, I., Nauschnegg, K., Paechter, M., Lackner, H. K., Goswami, N., & Schulter, G. (2010). Trait and state positive affect and cardiovascular recovery from experimental academic stress. *Biological Psychology*, *83*(2), 108–115. https://doi.org/10.1016/j.biopsycho.2009.11.008

Papousek, I., Schulter, G., & Premsberger, E. (2002). Dissociated autonomic regulation during stress and physical complaints. *Journal of Psychosomatic Research*, *52*(4), 257–266. https://doi.org/10.1016/S0022-3999(02)00298-2

Park, G., Moon, E., Kim, D.-W., & Lee, S.-H. (2012). Individual differences in cardiac vagal tone are associated with differential neural responses to facial expressions at different spatial frequencies: An ERP and sLORETA study. *Cognitive, Affective, and Behavioral Neuroscience*, *12*(4), 777–793. https://doi.org/10.3758/s13415-012-0111-0

Park, G., Van Bavel, J. J., Vasey, M. W., Egan, E. J. L., & Thayer, J. F. (2012). From the heart to the mind's eye: Cardiac vagal tone is related to visual perception of fearful faces at high spatial frequency. *Biological Psychology*, *90*(2), 171–178. https://doi.org/10.1016/j.biopsycho.2012.02.012

Park, G., Van Bavel, J. J., Vasey, M. W., & Thayer, J. F. (2013). Cardiac vagal tone predicts attentional engagement to and disengagement from fearful faces. *Emotion*, *13*(4), 645–656. https://doi.org/10.1037/a0032971

Park, G., Van Bavel, J. J., Vasey, M. W., & Thayer, J. F. (2012). Cardiac vagal tone predicts inhibited attention to fearful faces. *Emotion*, *12*(6), 1292–1302. https://doi.org/10.1037/a0028528

Park, G., Vasey, M. W., Van Bavel, J. J., & Thayer, J. F. (2013). Cardiac vagal tone is correlated with selective attention to neutral distractors under load. *Psychophysiology*, *50*(4), 398–406. https://doi.org/10.1111/psyp.12029

Park, S. B., Lee, B. C., & Jeong, K. S. (2007). Standardized tests of heart rate variability for autonomic function tests in healthy koreans. *International Journal of Neuroscience*, *117*(12), 1707–1717. https://doi.org/10.1080/00207450601050097

Patra, S., & Telles, S. (2010). Heart rate variability during sleep following the practice of cyclic meditation and supine rest. *Applied Psychophysiology Biofeedback*, *35*(2), 135–140. https://doi.org/10.1007/s10484-009-9114-1

Patron, E., Messerotti Benvenuti, S., Favretto, G., Valfrè, C., Bonfà, C., Gasparotto, R., & Palomba, D. (2012). Association between depression and heart rate variability in patients after cardiac surgery: A pilot study. *Journal of Psychosomatic Research*, *73*(1), 42–46. https://doi.org/10.1016/j.jpsychores.2012.04.013

Paul, M., & Garg, K. (2012). The effect of heart rate variability biofeedback on performance psychology of basketball players. *Applied Psychophysiology Biofeedback*, *37*(2), 131–144. https://doi.org/10.1007/s10484-012-9185-2

Pauls, C. A., & Stemmler, G. (2003). Repressive and defensive coping during fear and anger. *Emotion*, *3*(3), 284–302. https://doi.org/10.1037/1528-3542.3.3.284

Pellissier, S., Dantzer, C., Canini, F., Mathieu, N., & Bonaz, B. (2010). Psychological adjustment and autonomic disturbances in inflammatory bowel diseases and irritable bowel syndrome. *Psychoneuroendocrinology*, *35*(5), 653–662. https://doi.org/10.1016/j.psyneuen.2009.10.004

Peng, S.-M., Koo, M., & Yu, Z.-R. (2009). Effects of music and essential oil inhalation on cardiac autonomic balance in healthy individuals. *The Journal of Alternative and Complementary Medicine*, *15*(1), 53–57. https://doi.org/10.1089/acm.2008.0243

Penttilä, J., Syvälahti, E., Hinkka, S., Kuusela, T., & Scheinin, H. (2001). The effects of amitriptyline, citalopram and reboxetine on autonomic nervous system: A randomised placebo-controlled study on healthy volunteers. *Psychopharmacology*, *154*(4), 343–349. https://doi.org/10.1007/s002130000664

Perakakis, P., Taylor, M., Martinez-Nieto, E., Revithi, I., & Vila, J. (2009). Breathing frequency bias in fractal analysis of heart rate variability. *Biological Psychology*, *82*(1), 82–88. https://doi.org/10.1016/j.biopsycho.2009.06.004

Perseguini, N. M., Takahashi, A. C. M., Rebelatto, J. R., Silva, E., Borghi-Silva, A., Porta, A., … Catai, A. M. (2011). Spectral and symbolic analysis of the effect of gender and postural change on cardiac autonomic modulation in healthy elderly subjects. *Brazilian Journal of Medical and Biological Research*, *44*(1), 29–37. https://doi.org/10.1590/S0100-879X2010007500137

Petrowski, K., Herold, U., Joraschky, P., Mück-Weymann, M., & Siepmann, M. (2010). The effects of psychosocial stress on heart rate variability in panic disorder. *German Journal of Psychiatry*, *13*(2), 66–73.

Petrowski, K., Wintermann, G.-B., Joraschky, P., & Siepmann, M. (2011). HPA axis activity under psychosocial stress in patients with acute and remitted panic disorder. *German Journal of Psychiatry*, *14*(2), 72–79.

Phillips, R. O., Fyhri, A., & Sagberg, F. (2011). Risk compensation and bicycle helmets. *Risk Analysis*, *31*(8), 1187–1195. https://doi.org/10.1111/j.1539-6924.2011.01589.x

Pittig, A., Arch, J. J., Lam, C. W. R., & Craske, M. G. (2013). Heart rate and heart rate variability in panic, social anxiety, obsessive-compulsive, and generalized anxiety disorders at baseline and in response to relaxation and hyperventilation. *International Journal of Psychophysiology*, *87*(1), 19–27. https://doi.org/10.1016/j.ijpsycho.2012.10.012

Pollatos, O., Dietel, A., Herbert, B. M., Wankner, S., Wachsmuth, C., Henningsen, P., & Sack, M. (2011). Blunted autonomic reactivity and increased pain tolerance in somatoform patients. *Pain*, *152*(9), 2157–2164. https://doi.org/10.1016/j.pain.2011.05.024

Pollatos, O., Füstös, J., & Critchley, H. D. (2012). On the generalised embodiment of pain: How interoceptive sensitivity modulates cutaneous pain perception. *Pain*, *153*(8), 1680–1686. https://doi.org/10.1016/j.pain.2012.04.030

Pollatos, O., Herbert, B. M., Füstös, J., Weimer, K., Enck, P., & Zipfel, S. (2012). Food deprivation sensitizes pain perception. *Journal of Psychophysiology*, *26*(1), 1–9. https://doi.org/10.1027/0269-8803/a000062

Pollatos, O., Herbert, B. M., Wankner, S., Dietel, A., Wachsmuth, C., Henningsen, P., & Sack, M. (2011). Autonomic imbalance is associated with reduced facial recognition in somatoform disorders. *Journal of Psychosomatic Research*, *71*(4), 232–239. https://doi.org/10.1016/j.jpsychores.2011.03.012

Ponnusamy, A., Marques, J. L. B., & Reuber, M. (2011). Heart rate variability measures as biomarkers in patients with psychogenic nonepileptic seizures: Potential and limitations. *Epilepsy and Behavior*, *22*(4), 685–691. https://doi.org/10.1016/j.yebeh.2011.08.020

Poole, L., Hamer, M., Wawrzyniak, A. J., & Steptoe, A. (2011). The effects of exercise withdrawal on mood and inflammatory cytokine responses in humans. *Stress*, *14*(4), 439–447. https://doi.org/10.3109/10253890.2011.557109

Pradhan, C., Yashavantha, B. S., Pal, P. K., & Sathyaprabha, T. N. (2008). Spinocerebellar ataxias type 1, 2 and 3: A study of heart rate variability. *Acta Neurologica Scandinavica*, *117*(5), 337–342. https://doi.org/10.1111/j.1600-0404.2007.00945.x

Prinsloo, G. E., Derman, W. E., Lambert, M. I., & Laurie Rauch, H. G. (2013). The effect of a single session of short duration biofeedback-induced deep breathing on measures of heart rate variability during laboratory-induced cognitive stress: A pilot study. *Applied Psychophysiology Biofeedback*, *38*(2), 81–90. https://doi.org/10.1007/s10484-013-9210-0

Prinsloo, G. E., Rauch, H. G. L., Karpul, D., & Derman, W. E. (2013). The effect of a single session of short duration heart rate variability biofeedback on EEG: a pilot study. *Applied Psychophysiology and Biofeedback*, *38*(1), 45–56. https://doi.org/10.1007/s10484-012-9207-0

Prinsloo, G. E., Rauch, H. G. L., Lambert, M. I., Muench, F., Noakes, T. D., & Derman, W. E. (2010). The effect of short duration heart rate variability (HRV) biofeedback on cognitive performance during laboratory induced cognitive stress. *Applied Cognitive Psychology*, *25*(5), 792–801. https://doi.org/10.1002/acp.1750

Quintana, D. S., Guastella, A. J., Outhred, T., Hickie, I. B., & Kemp, A. H. (2012). Heart rate variability is associated with emotion recognition: Direct evidence for a relationship between the autonomic nervous system and social cognition. *International Journal of Psychophysiology*, *86*(2), 168–172. https://doi.org/10.1016/j.ijpsycho.2012.08.012

Rachow, T., Berger, S., Boettger, M. K., Schulz, S., Guinjoan, S. M., Yeragani, V. K., … Bär, K. J. (2011). Nonlinear relationship between electrodermal activity and heart rate variability in patients with acute schizophrenia. *Psychophysiology*, *48*(10), 1323–1332. https://doi.org/10.1111/j.1469-8986.2011.01210.x

Raghuraj, P., & Telles, S. (2008). Immediate effect of specific nostril manipulating yoga breathing practices on autonomic and respiratory variables. *Applied Psychophysiology Biofeedback*, *33*(2), 65–75. https://doi.org/10.1007/s10484-008-9055-0

Rauscher, G., DeGiorgio, A. C., Miller, P. R., & DeGiorgio, C. M. (2011). Sudden unexpected death in epilepsy associated with progressive deterioration in heart rate variability. *Epilepsy and Behavior*, *21*(1), 103–105. https://doi.org/10.1016/j.yebeh.2011.03.002

Ravaja, N. (2004). Effects of a small talking facial image on autonomic activity: The moderating influence of dispositional BIS and BAS sensitivities and emotions. *Biological Psychology*, *65*(2), 163–183. https://doi.org/10.1016/S0301-0511(03)00078-4

Ray, W. J., Sabsevitz, D., de Pascalis, V., Quigley, K. S., Aikins, D., & Tubbs, M. (2000). Cardiovascular reactivity during hypnosis and hypnotic susceptibility: Three studies of heart rate variability. *International Journal of Clinical and Experimental Hypnosis*, *48*(1), 22–31. https://doi.org/10.1080/00207140008410358

Raymond, J., Sajid, I., Parkinson, L. A., & Gruzelier, J. H. (2005). Biofeedback and dance performance: A preliminary investigation. *Applied Psychophysiology Biofeedback*, *30*(1), 65–73. https://doi.org/10.1007/s10484-005-2175-x

Rebelo, A. C., Tamburús, N., Salviati, M., Celante, V., Takahashi, A., de Sá, M. F., … Silva, E. (2011). Influence of third-generation oral contraceptives on the complexity analysis and symbolic dynamics of heart rate variability. *The European Journal of Contraception and Reproductive Health Care*, *16*(4), 289–297. https://doi.org/10.3109/13625187.2011.591217

Reinders, A. A. T. S., Nijenhuis, E. R. S., Quak, J., Korf, J., Haaksma, J., Paans, A. M. J., … den Boer, J. A. (2006). Psychobiological characteristics of dissociative identity disorder: A symptom provocation study. *Biological Psychiatry*, *60*(7), 730–740. https://doi.org/10.1016/j.biopsych.2005.12.019

Reyes del Paso, G. A., Garrido, S., Pulgar, Á., & Duschek, S. (2011). Autonomic cardiovascular control and responses to experimental pain stimulation in fibromyalgia syndrome. *Journal of Psychosomatic Research*, *70*(2), 125–134. https://doi.org/10.1016/j.jpsychores.2010.09.012

Reyes Del Paso, G. A., Garrido, S., Pulgar, Á., Martín-Vázquez, M., & Duschek, S. (2010). Aberrances in autonomic cardiovascular regulation in fibromyalgia syndrome and their relevance for clinical pain reports. *Psychosomatic Medicine*, *72*(27), 462–470. https://doi.org/10.1097/PSY.0b013e3181da91f1

Reynard, A., Gevirtz, R. N., Berlow, R., Brown, M., & Boutelle, K. (2011). Heart rate variability as a marker of self-regulation. *Applied Psychophysiology Biofeedback*, *36*(3), 209–215. https://doi.org/10.1007/s10484-011-9162-1

Rieber, N., Betz, L., Enck, P., Muth, E., Nikendei, C., Schrauth, M., … Zipfel, S. (2009). Effects of medical training scenarios on heart rate variability and motivation in students and simulated patients. *Medical Education*, *43*(6), 553–556. https://doi.org/10.1111/j.1365-2923.2009.03374.x

Riese, H., Rosmalen, J. G. M., Ormel, J., Van Roon, A., Oldehinkel, A. J., & Rijsdijk, F. V. (2007). The genetic relationship between neuroticism and autonomic function in female twins. *Psychological Medicine*, *37*(2), 257–267. https://doi.org/10.1017/S0033291706009160

Riganello, F., Candelieri, A., Quintieri, M., Conforti, D., & Dolce, G. (2010). Heart rate variability: An index of brain processing in vegetative state? An artificial intelligence, data mining study. *Clinical Neurophysiology*, *121*(12), 2024–2034. https://doi.org/10.1016/j.clinph.2010.05.010

Riganello, F., Candelieri, A., Quintieri, M., & Dolce, G. (2010). Heart rate variability, emotions, and music. *Journal of Psychophysiology*, *24*(2), 112–119. https://doi.org/10.1027/0269-8803/a000021

Riganello, F., Quintieri, M., Candelieri, A., Conforti, D., & Dolce, G. (2008). Heart rate response to music: An artificial intelligence study on healthy and traumatic brain-injured subjects. *Journal of Psychophysiology*, *22*(4), 166–174. https://doi.org/10.1027/0269-8803.22.4.166

Rochman, D., & Diamond, G. M. (2008). From unresolved anger to sadness: Identifying physiological correlates. *Journal of Counseling Psychology*, *55*(1), 96–105. https://doi.org/10.1037/0022-0167.55.1.96

Rockliff, H., Gilbert, P., McEwan, K., Lightman, S., & Glover, D. (2008). A pilot exploration of heart rate variability and salivary cortisol responses to compassion-focused imagery. *Clinical Neuropsychiatry*, *5*(3), 132–139.

Rodríguez-Ruiz, S., Guerra, P. M., Moreno, S., Carmen Fernández, M., & Vila, J. (2012). Heart rate variability modulates eye-blink startle in women with bulimic symptoms. *Journal of Psychophysiology*, *26*(1), 10–19. https://doi.org/10.1027/0269-8803/a000064

Rodríguez-Ruiz, S., Ruiz-Padial, E., Vera, N., Fernández, C., Anllo-Vento, L., & Vila, J. (2009). Effect of heart rate variability on defensive reaction and eating disorder symptomatology in chocolate cravers. *Journal of Psychophysiology*, *23*(3), 95–103. https://doi.org/10.1027/0269-8803.23.3.95

Roeser, K., Obergfell, F., Meule, A., Vögele, C., Schlarb, A. A., & Kübler, A. (2012). Of larks and hearts — morningness/eveningness, heart rate variability and cardiovascular stress response at different times of day. *Physiology and Behavior*, *106*(2), 151–157. https://doi.org/10.1016/j.physbeh.2012.01.023

Rohleder, N., Wolf, J. M., Maldonado, E. F., & Kirschbaum, C. (2006). The psychosocial stress-induced increase in salivary alpha-amylase is independent of saliva flow rate. *Psychophysiology*, *43*(6), 645–652. https://doi.org/10.1111/j.1469-8986.2006.00457.x

Rossi Caruso, F. C., Arena, R., Mendes, R. G., Reis, M. S., Papa, V., & Borghi-Silva, A. (2011). Heart rate autonomic responses during deep breathing and walking in hospitalised patients with chronic heart failure. *Disability and Rehabilitation*, *33*(9), 751–757. https://doi.org/10.3109/09638288.2010.511420

Ruiz-Padial, E., Sollers, J. J., Vila, J., & Thayer, J. F. (2003). The rhythm of the heart in the blink of an eye: Emotion-modulated startle magnitude covaries with heart rate variability. *Psychophysiology*, *40*(2), 306–313. https://doi.org/10.1111/1469-8986.00032

Russoniello, C. V, O'Brien, K., & Parks, J. M. (2009). The effectiveness of casual video games in improving mood and decreasing stress. *Journal of Cybertherapy and Rehabilitation*, *2*(1), 53–66.

Russoniello, C. V, O'Brien, K., & Parks, J. M. (2009). EEG, HRV and psychological correlates while playing bejeweled II: A randomized controlled study. *Studies in Health Technology and Informatics*, *144*, 189–192. https://doi.org/10.3233/978-1-60750-017-9-189

Ryu, K., & Myung, R. (2005). Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic. *International Journal of Industrial Ergonomics*, *35*(11), 991–1009. https://doi.org/10.1016/j.ergon.2005.04.005

Sack, M., Lempa, W., & Lamprecht, F. (2007). Assessment of psychophysiological stress reactions during a traumatic reminder in patients treated with EMDR. *Journal of EMDR Practice and Research*, *1*(1), 15–23. https://doi.org/10.1891/1933-3196.1.1.15

Sack, M., Lempa, W., Steinmetz, A., Lamprecht, F., & Hofmann, A. (2008). Alterations in autonomic tone during trauma exposure using eye movement desensitization and reprocessing (EMDR)-Results of a preliminary investigation. *Journal of Anxiety Disorders*, *22*(7), 1264–1271. https://doi.org/10.1016/j.janxdis.2008.01.007

Sakakibara, S., Honma, H., Kohsaka, M., Fukuda, N., Kawai, I., Kobayashi, R., & Koyama, T. (2000). Autonomic nervous function after evening bright light therapy: Spectral analysis of heart rate variability. *Psychiatry and Clinical Neurosciences*, *54*(3), 363–364. https://doi.org/10.1046/j.1440-1819.2000.00716.x

Sakuragi, S., & Sugiyama, Y. (2011). Effect of partition board color on mood and autonomic nervous function. *Perceptual and Motor Skills*, *113*(3), 941–956. https://doi.org/10.2466/03.14.22.PMS.113.6.941-956

Santarcangelo, E. L., Paoletti, G., Balocchi, R., Scattina, E., Ghelarducci, B., & Varanini, M. (2012). Watching neutral and threatening movies: Subjective experience and autonomic responses in subjects with different hypnotizability levels. *International Journal of Psychophysiology*, *84*(1), 59–64. https://doi.org/10.1016/j.ijpsycho.2012.01.010

Santos-Hiss, M. D. B., Melo, R. C., Neves, V. R., Hiss, F. C., Verzola, R. M. M., Silva, E., … Catai, A. M. (2011). Effects of progressive exercise during phase I cardiac rehabilitation on the heart rate variability of patients with acute myocardial infarction. *Disability and Rehabilitation*, *33*(10), 835–842. https://doi.org/10.3109/09638288.2010.514016

Sarang, P., & Telles, S. (2006). Effects of two yoga based relaxation techniques on heart rate variability (HRV). *International Journal of Stress Management*, *13*(4), 460–475. https://doi.org/10.1037/1072-5245.13.4.460

Sauder, K. A., Johnston, E. R., Skulas-Ray, A. C., Campbell, T. S., & West, S. G. (2012). Effect of meal content on heart rate variability and cardiovascular reactivity to mental stress. *Psychophysiology*, *49*(4), 470–477. https://doi.org/10.1111/j.1469-8986.2011.01335.x

Saus, E. R., Johnsen, B. H., Eid, J., Riisem, P. K., Andersen, R., & Thayer, J. F. (2006). The effect of brief situational awareness training in a police shooting simulator: An experimental study. *Military Psychology*, *18*(Suppl.), S3–S21. https://doi.org/10.1207/s15327876mp1803s_2

Saus, E. R., Johnsen, B. H., Eid, J., & Thayer, J. F. (2012). Who benefits from simulator training: Personality and heart rate variability in relation to situation awareness during navigation training. *Computers in Human Behavior*, *28*(4), 1262–1268. https://doi.org/10.1016/j.chb.2012.02.009

Sbarra, D. A., & Borelli, J. L. (2013). Heart rate variability moderates the association between attachment avoidance and self-concept reorganization following marital separation. *International Journal of Psychophysiology*, *88*(3), 253–260. https://doi.org/10.1016/j.ijpsycho.2012.04.004

Scarpa, A., Fikretoglu, D., & Luscher, K. (2000). Community violence exposure in a young adult sample: II. Psychophysiology and aggressive behavior. *Journal of Community Psychology*, *28*(4), 417–425. https://doi.org/10.1002/1520-6629(200007)28:4<417::AID-JCOP4>3.0.CO;2-L

Scarpa, A., & Ollendick, T. H. (2003). Community violence exposure in a young adult sample: III. Psychophysiology and victimization interact to affect risk for aggression. *Journal of Community Psychology*, *31*(4), 321–338. https://doi.org/10.1002/jcop.10058

Schachinger, H., Blumenthal, T. D., Richter, S., Savaskan, E., Wirz-Justice, A., & Kräuchi, K. (2008). Melatonin reduces arousal and startle responsiveness without influencing startle habituation or affective startle modulation in young women. *Hormones and Behavior*, *54*(2), 258–262. https://doi.org/10.1016/j.yhbeh.2008.03.013

Schapkin, S. A., Freude, G., Gajewski, P. D., Wild-Wall, N., & Falkenstein, M. (2012). Effects of working memory load on performance and cardiovascular activity in younger and older workers. *International Journal of Behavioral Medicine*, *19*(3), 359–371. https://doi.org/10.1007/s12529-011-9181-6

Schellekens, J. M. H., Sijtsma, G. J., Vegter, E., & Meijman, T. F. (2000). Immediate and delayed after-effects of long lasting mentally demanding work. *Biological Psychology*, *53*(1), 37–56. https://doi.org/10.1016/S0301-0511(00)00039-9

Schmeichel, B., Demaree, H. A., Robinson, J., & Pu, J. (2006). Ego depletion by response exaggeration. *Journal of Experimental Social Psychology*, *42*(1), 95–102. https://doi.org/10.1016/j.jesp.2005.02.005

Solberg Nes, L., Carlson, C. R., Crofford, L. J., Leeuw, R. De, & Segerstrom, S. C. (2010). Self-regulatory deficits in fibromyalgia and temporomandibular disorders. *Pain*, *151*(1), 37–44. https://doi.org/10.1016/j.pain.2010.05.009

Spiegelhalder, K., Fuchs, L., Ladwig, J., Kyle, S. D., Nissen, C., Voderholzer, U., … Riemann, D. (2011). Heart rate and heart rate variability in subjectively reported insomnia. *Journal of Sleep Research*, *20*, 137–145. https://doi.org/10.1111/j.1365-2869.2010.00863.x

Tang, R., Tegeler, C., Larrimore, D., Cowgill, S., & Kemper, K. J. (2010). Improving the well-being of nursing leaders through healing touch training. *Journal of Alternative and Complementary Medicine*, *16*(8), 837–841. https://doi.org/10.1089/acm.2009.0558

Thompson, L. F., Sebastianelli, J. D., & Murray, N. P. (2009). Monitoring online training behaviors: Awareness of electronic surveillance hinders e-learners. *Journal of Applied Social Psychology*, *39*(9), 2191–2212. https://doi.org/10.1111/j.1559-1816.2009.00521.x

Trachani, E., Constantoyannis, C., Sakellaropoulos, G. C., Stavrinou, M. L., Nikiforidis, G., & Chroni, E. (2012). Heart rate variability in Parkinson's disease unaffected by deep brain stimulation. *Acta Neurologica Scandinavica*, *126*(1), 56–61. https://doi.org/10.1111/j.1600-0404.2011.1605.x

Treister, R., Kliger, M., Zuckerman, G., Aryeh, I. G., & Eisenberg, E. (2012). Differentiating between heat pain intensities: The combined effect of multiple autonomic parameters. *Pain*, *153*(9), 1807–1814. https://doi.org/10.1016/j.pain.2012.04.008

Tsai, Y.-S., Lai, F.-C., Chen, S.-R., & Jeng, C. (2011). The influence of physical activity level on heart rate variability among asthmatic adults. *Journal of Clinical Nursing*, *20*(1–2), 111–118. https://doi.org/10.1111/j.1365-2702.2010.03397.x

Tschacher, W., Greenwood, S., Kirchberg, V., Wintzerith, S., van den Berg, K., & Tröndle, M. (2012). Physiological correlates of aesthetic perception of artworks in a museum. *Psychology of Aesthetics, Creativity, and the Arts*, *6*(1), 96–103. https://doi.org/10.1037/a0023845

Udo, T., Bates, M. E., Mun, E. Y., Vaschillo, E., Vaschillo, B., Lehrer, P. M., & Ray, S. (2009). Gender differences in acute alcohol effects on self-regulation of arousal in response to emotional and alcohol-related picture cues. *Psychology of Addictive Behaviors*, *23*(2), 196–204. https://doi.org/10.1037/a0015015

Udupa, K., Thirthalli, J., Sathyaprabha, T. N., Kishore, K. R., Raju, T. R., & Gangadhar, B. N. (2011). Differential actions of antidepressant treatments on cardiac autonomic alterations in depression: A prospective comparison. *Asian Journal of Psychiatry*, *4*(2), 100–106. https://doi.org/10.1016/j.ajp.2011.02.006

van der Kooy, K. G., van Hout, H. P. J., van Marwijk, H. W. J., de Haan, M., Stehouwer, C. D. A., & Beekman, A. T. F. (2006). Differences in heart rate variability between depressed and non-depressed elderly. *International Journal of Geriatric Psychiatry*, *21*(2), 147–150. https://doi.org/10.1002/gps.1439

van Drunen, A., van den Broek, E. L., Spink, A. J., & Heffelaar, T. (2009). Exploring workload and attention measurements with uLog mouse data. *Behavior Research Methods*, *41*(3), 868–875. https://doi.org/10.3758/BRM.41.3.868

van Zanten, J. J. V., De Boer, D., Harrison, L. K., Ring, C., Carroll, D., Willemsen, G., … Geus, E. J. C. (2002). Competitiveness and hemodynamic reactions to competition. *Psychophysiology*, *39*(6), 759–766. https://doi.org/10.1111/1469-8986.3960759

Vasudev, A., O'Brien, J. T., Tan, M. P., Parry, S. W., & Thomas, A. J. (2011). A study of orthostatic hypotension, heart rate variability and baroreflex sensitivity in late-life depression. *Journal of Affective Disorders*, *131*(1–3), 374–378. https://doi.org/10.1016/j.jad.2010.11.001

Vögele, C., Hilbert, A., & Tuschen-Caffier, B. (2009). Dietary restriction, cardiac autonomic regulation and stress reactivity in bulimic women. *Physiology and Behavior*. https://doi.org/10.1016/j.physbeh.2009.05.018

Whang, M. C., Lim, J. S., & Boucsein, W. (2003). Preparing computers for affective communication: A psychological concept and preliminary results. *Human Factors*, *45*(4), 623–634. https://doi.org/10.1518/hfes.45.4.623.27095

Whited, M. C., Wheat, A. L., & Larkin, K. T. (2010). The influence of forgiveness and apology on cardiovascular reactivity and recovery in response to mental stress. *Journal of Behavioral Medicine*, *33*(4), 293–304. https://doi.org/10.1007/s10865-010-9259-7

Williams, E. D., Steptoe, A., Chambers, J. C., & Kooner, J. S. (2011). Ethnic and gender differences in the relationship between hostility and metabolic and autonomic risk factors for coronary heart disease. *Psychosomatic Medicine*, *73*(1), 53–58. https://doi.org/10.1097/PSY.0b013e3181fd944c

Xu, J., & Montague, E. (2012). Psychophysiology of the passive user: Exploring the effect of technological conditions and personality traits. *International Journal of Industrial Ergonomics*, *42*(5), 505–512. https://doi.org/10.1016/j.ergon.2012.07.007

Yeragani, V. K., & Rao, R. (2003). Effect of nortriptyline and paroxetine on measures of chaos of heart rate time series in patients with panic disorder. *Journal of Psychosomatic Research*, *55*(6), 507–513. https://doi.org/10.1016/S0022-3999(03)00023-0

Zucker, T. L., Samuelson, K. W., Muench, F., Greenberg, M. A., & Gevirtz, R. N. (2009). The effects of respiratory sinus arrhythmia biofeedback on heart rate variability and posttraumatic stress disorder symptoms: A pilot study. *Applied Psychophysiology Biofeedback*, *34*(2), 135–143. https://doi.org/10.1007/s10484-009-9085-2

8. Curriculum Vitae

Persönliche Informationen

Name	Stefan Uhlig
Geburtsdatum und Ort	26. März 1987 in Karl-Marx-Stadt
Nationalität	deutsch
Anschrift	Hübschmannstraße 26, 09112 Chemnitz

Kontakt (dienstlich)

Anschrift	Technische Universität Chemnitz Fakultät für Human und Sozialwissenschaften Institut für Psychologie Professur für Allgemeine und Biopsychologie Wilhelm-Raabe-Straße 43, 09120 Chemnitz
Email	stefan.uhlig@allpsy2.de
Telefon/Fax	+49 371 531-39636 / +49 371 531-839636

Bildungsweg

August 1993 – Juli 1997	Jan-Amos-Comenius Grundschule in Chemnitz
August 1997 – Juli 2005	Johannes-Kepler-Gymnasium in Chemnitz Abschluss: Abitur (Geschichte, Deutsch, Mathematik, Biologie), Abschlussnote: 1,7
Oktober 2006 – August 2009	Studium an der Technischen Universität Chemnitz Studiengang: B. Sc. Psychologie Abschlussnote: 1,2
Oktober 2009 – September 2011	Studium an der Technischen Universität Chemnitz Studiengang: M. Sc. Psychologie Abschlussnote: 1,0

Praktische Tätigkeiten/Jobs

Oktober 2005 – Juni 2006	Zivildienst im Klinikum Chemnitz gGmbH im Bereich Patiententransport und Pflege
November – Dezember 2007	Aushilfstätigkeit bei OHG Fegro/Selgros-Großhandel mbH & Co.: Arbeit im Kassenbereich
August – September 2008	6-wöchiges Praktikum im KfH Nierenzentrum für Kinder und Jugendliche Leipzig
Juli 2009	3-wöchiges Praktikum im sozialpsychiatrischen Dienst der Stadt Chemnitz
Januar 2010 – Dez. 2010	Mentorentätigkeit für den Huckepack-Kinderförderung e.V.
Oktober 2011 – Dez. 2011	Sozialpsychiatrischer Dienst der Stadt Chemnitz
seit Oktober 2011	Wissenschaftlicher Mitarbeiter der Professur für Allgemeine und Biopsychologie (Forschung, Lehre), TU Chemnitz
seit 2015	geschäftsführender Partner des Institutes für angewandte Wissenschaft

Soziales/fachliches Engagement

Juli 2007 – Juni 2014	Ehrenamtlicher Übungsleiter der U11/U13/U15-Junioren des TSV Germania Chemnitz 08, Abteilung Fußball
Januar 2008 – März 2011	Studentische Hilfskraft (Professur für Allgemeine und Biopsychologie)
seit November 2010	Dozententätigkeit für den Huckepack-Kinderförderung e.V.
Juni 2011 – September 2011	Wissenschaftliche Hilfskraft an der Professur für Allgemeine und Biopsychologie, Projekt „Get Started“
seit 2013	Dozententätigkeit für die TUCed GmbH in den Studiengängen „Integrative Lerntherapie“ und „Gerontopsychologie“
seit 2015	Psychosoziale Betreuung der Fox-Schülercamps (Kindervereinigung Sachsen e.V.)
seit 2017	stellvertretender Vorstandsvorsitzender des Huckepack-Kinderförderung e. V.

Lehre

Seminar	Biologische Psychologie (WS 17/18)
Seminar	Grundlagen und Anwendungsbereiche psychologischer Gesprächsführung (WS 12/13, SS 13, SS 14, SS 15, WS 15/16, SS 16, WS 16/17)
Forschungskolloquium	Aktuelle Forschungsarbeiten in der Motivations- und Emotionspsychologie (WS 11/12, SS 12, WS 12/13, SS 13, WS 13/14, SS 14, WS 14/15, SS 15, WS 15/16, SS 16, WS 16/17)
Seminar	Soft Skills: Gesprächsführung und Präsentationstechniken (SS 2015)
Seminar	Empirisch-experimentelles Forschen (WS 13/14, WS 14/15)

Kompetenzen/Auszeichnungen

Fremdsprachen	Gute Englischkenntnisse in Wort und Schrift Latein (Latinum)
Auszeichnungen	Lehrpreis der Fakultät für Human- und Sozialwissenschaften der Technischen Universität Chemnitz, Wintersemester 2015/2016 Abschluss des Master-Studiums mit dem besten Jahrgangs-Ergebnis (Auszeichnung: 12/2011)

9. List of Publications

9.1. Books, Book Chapters, (Conference) Paper, Theses

Uhlig, S., Meylan, A., & Rudolph, U. (2017). *A systematic review of short-term heart rate variability in psychological research: Toward unified methodological standards*. Manuscript in preparation.

Uhlig, S., Meylan, A., & Rudolph, U. (2017). *Reliability of short-term measurements of heart rate variability: Findings from a longitudinal study*. Manuscript submitted for publication.

Uhlig, S., Winter, N., Meylan, A., & Rudolph, U. (2017). *Stress and coping in school: Heart rate variability, self-reported stress, school achievement*. Manuscript submitted for publication.

Körner, A., Rudolph, U., Uhlig, S., & David, A. (in press). Doping im Sport - Moralische und motivationale Aspekte des Betrugs. In A. Schneider, J. Köhler, & F. Schumann (Eds.), *Werte im Sport*. Wiesbaden: Springer VS.

Körner, A., Uhlig, S., & Sperber, E. (2018). Langfristig gesund im Beruf: Auf dem Weg zu einem Kompetenzmodell für die Akteure der Sozialwirtschaft Südwest-Sachsens. In S. Kauffeld, & F. Frerichs (Eds.), *Kompetenzmanagement in kleinen und mittelständischen Unternehmen* (pp. 55–70). Berlin: Springer. doi: 10.1007/978-3-662-54830-1_4

Uhlig, S., & Körner, A. (2018). Kompetenzentwicklungsbedarfe in der Sozialwirtschaft: Das Belastungs- und Beanspruchungserleben bei freien Trägern in Südwest-Sachsen. In S. Kauffeld, & F. Frerichs (Eds.), *Kompetenzmanagement in kleinen und mittelständischen Unternehmen* (pp. 15–35). Berlin: Springer. doi: 10.1007/978-3-662-54830-1_2

Körner, A., Schade, H., & Uhlig, S. (2017). Zwischen Absentismus und Präsentismus – Belastungs- und Beanspruchungserleben in der Sozialwirtschaft. In A. Schorr (Ed.), *Health Psychology 2017* (pp. 25). Lengerich: Pabst.

Uhlig, S., David, A., Körner, A., & Rudolph, U. (2016). *Leitfaden Evaluation: Evaluationen verstehen, bewerten und planen.* Frankfurt am Main: Deutscher Fußballbund e. V.

Rudolph, U., Körner, A., David, A., & Uhlig, S. (2016). Der Fußball und die Fans: Fanarbeit in einem komplexen Netzwerk. In A. Schneider, J. Köhler, & F. Schumann (Eds.), *Fanverhalten im Sport.* Wiesbaden: Springer VS.

Körner, A., & Uhlig, S. (2016). Berufswege und Personalentwicklung in der Sozialwirtschaft – Welche Kompetenzen brauchen Fachkräfte um lange, gesund und motiviert im Job zu bleiben? In Gesellschaft für Arbeitswissenschaft (GfA) (Ed.), *Arbeit in komplexen Systemen. Digital, vernetzt, human?! Bericht zum 62. Frühjahrskongress vom 2.-4. März 2016.* Dortmund: GfA-Press. doi:10.13140/RG.2.1.1501.6725

Rudolph, U., Uhlig, S., David, A., Helbig, J-P., & Kahlert, B. (2014). *Fußballzuschauer Gewalt Rechtsextremismus – gewalttätiges und rechtsextremistisches Verhalten von Fußballzuschauern – Ursachen, Erfassung und Gegenmaßnahmen*. Bundeszentrale für politische Bildung: Regiestelle „Zusammenhalt durch Teilhabe“.

Helbig, J-P., Uhlig, S., & Rudolph, U., (2014). *Fanprojekte in Sachsen: Eine Bestandsaufnahme der Arbeit und Struktur der sozialpädagogisch arbeitenden Fanprojekte.* Bundeszentrale für politische Bildung: Regiestelle „Zusammenhalt durch Teilhabe“.

Uhlig, S. (2011). *Der Einfluss von Selbstwirksamkeit auf die Effekte eines sensomotorischen Trainings bei Patienten mit IPS* (unpublished master’s thesis). Technische Universität Chemnitz, Chemnitz.

Uhlig, S. (2009). *HUCKEPACK - Ein Manual für ErzieherInnen zur Prävention aggressiven Verhaltens im Vorschulalter* (unpublished bachelor’s thesis). Technische Universität Chemnitz, Chemnitz.

9.2. Talks and Presentations

Körner, A., David, A., Uhlig, S., & Rudolph, U. (2017). *Phänomen e-Sport – Einflussfaktoren, erfolgskritische Variablen & Training.* Vortrag auf dem 4. Udo-Steinberg-Symposium, Mittweida, 24. Oktober 2017. doi:10.13140/RG.2.2.21551.23205

Körner, A., Rudolph, U., Uhlig, S., & David, A. (2016). *Doping im Sport – moralische und motivationale Aspekte des Betrugs.* Vortrag auf dem 3. Udo-Steinberg-Symposium, Mittweida, 14.-15. November 2016. doi:10.13140/RG.2.2.34973.00488

Uhlig, S., Körner, A., & Rudolph, U. (2016). *Belastungs- und Beanspruchungserleben in der Sozialwirtschaft: Die Situation freier Träger in Westsachsen.* Vortrag auf dem 50. Kongress der Deutschen Gesellschaft für Psychologie, Leipzig, 18.-22. September 2016.

Uhlig, S., Meylan, A., & Rudolph, U. (2016). *Herzratenvariabilität in psychologischen Kurzzeitmessungen: Ein zeitlich stabiles Maß?* Vortrag auf dem 50. Kongress der Deutschen Gesellschaft für Psychologie, Leipzig, 18.-22. September 2016.

Meylan, A., Uhlig, S., & Rudolph, U. (2016). *Herzratenvariabilität bei Kindern: Methodische Standards und Herausforderungen.* Vortrag auf dem 50. Kongress der Deutschen Gesellschaft für Psychologie, Leipzig, 18.-22. September 2016.

Körner, A., Uhlig, S., & Rudolph, U. (2016). *Motiviert und langfristig gesund im Beruf – Ein bedarfsgerechtes Kompetenzmodell für Akteure der Sozialwirtschaft Westsachsens.* Vortrag auf dem 50. Kongress der Deutschen Gesellschaft für Psychologie, Leipzig, 18.-22. September 2016.

Körner. A., & Uhlig, S. (2016). *Berufswege und Personalentwicklung in der Sozialwirtschaft – Welche Kompetenzen brauchen Fachkräfte um lange, gesund und motiviert im Job zu bleiben?* Vortrag auf dem 62. Frühjahrskongress der Gesellschaft für Arbeitswissenschaft (GfA), Aachen, 2.-4. März 2016.

10. Eidesstattliche Erklärung (affidavit)

Hiermit erkläre ich, Stefan Uhlig, dass ich die vorliegende Arbeit mit dem Titel

Heart Rate Variability: What Remains at the End of the Day?

[Herzratenvariabilität: Was bleibt am Ende des Tages übrig?]

selbstständig angefertigt und keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe. Entsprechend habe ich wörtlich oder sinngemäß übernommenes Gedankengut kenntlich gemacht.

Stefan Uhlig

Chemnitz, den